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ALGAE IN WATER SUPPLIES. AN ILLUSTRATED MANUAL ON THE IDENTIFICATION, SIGNIFICANCE, AND CONTROL OF ALGAE IN WATER SUPPLIES

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Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

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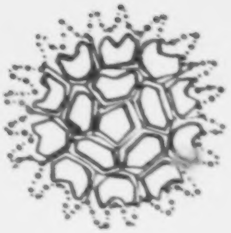

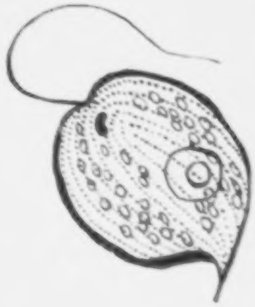

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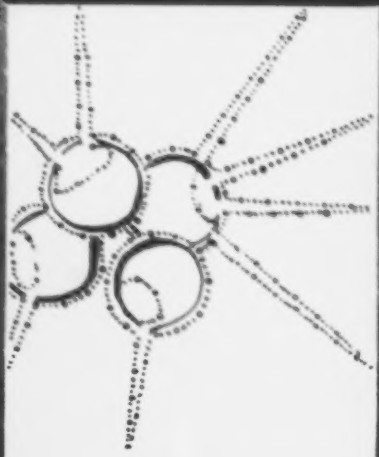

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ALGAE IN
WATER SUPPLIES

An Illustrated Manual on the Identification, Significance, and Control of Algae in Water Supplies

COLOR ILLUSTRATIONS REPRODUCED
IN BLACK AND WHITE

C. MERVIN PALMER

WITH AN INTRODUCTION BY CLARENCE M. TARZWELL
ILLUSTRATIONS IN COLOR BY HAROLD J. WALTER

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
Bureau of State Services • Division of Water Pollution Control
Robert A. Taft Sanitary Engineering Center

CINCINNATI, OHIO

I.

FOREWORD

This manual has been prepared for water analysts and others who deal with the many problems and effects associated with the presence of algae in water supplies. The need of an up-to-date concise account of the algae important in water supplies has been felt for some time, and the large demand for copies of a preliminary article[1] on the subject, published in June 1955, confirms this interest.

In the present state of our knowledge and with increasing activities in this field, any manual on algae can be only a broad forerunner of more specific handbooks on various phases of the subject. Workers will now have at least a concise general account, the absence of which has doubtless prevented many from making adequate analyses of the aquatic organisms belonging to this important group of plants.

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[1] *Public Works*, vol. 86 no. 6 pp. 107–120 (June 1955).

PREFACE

The available literature on algae has tended to be of two extreme types. Several recent treatises contain extensive scientific descriptions of algae of particular areas or are monographs of a single genus or group. These are excellent for academic studies and for encyclopedic and background references in applied phycology. At the other extreme are a considerable number of brief papers concerned with certain phases of problems, enumeration, or treatment of algae in water supplies. None of these are sufficient for use as guides in dealing with the recognition of the more important kinds of algae together with the interpretation and use of such information in the control or utilization of algae present in water supplies.

This manual has been prepared to help fill the need for more complete information on those algae important in water supplies and particularly to include a key, illustrations, and other aids needed for their identification. References to related literature are listed at the ends of the chapters in which they are cited.

There has also been an expanding interest in developing new industrial procedures where algae are utilized. This is in addition to various problems which they are responsible for in water treatment and water use. Together these interests have brought about an increasing demand for information on the algae which are involved.

The manual omits the many rare or uncommon algae as well as those growing in habitats other than water supplies. Only a limited amount of information is included on marine and estuarine algae; the bulk of the manual deals with the fresh-water forms.

It is not possible at present to refer to any single or standard procedure for the recording and counting of algae and for their control. We can merely point and work in that direction. With the desire growing for exchange of algological data by water treatment plants, and by many others concerned with algae, the need for standardized procedures is becoming more apparent.

In compiling this manual, the aid of many co-workers has been requested and has been generously given. Some of the work of correcting and critical reading of the manuscript has been assumed by several members of the staff of the Robert A. Taft Sanitary Engineering Center. Grateful acknowledgment for this service is given particularly to B. B. Berger, Chief of the Water Supply and Water Pollution Program, C. M. Tarzwell, Chief Aquatic Biologist, and R. T. Hyde, Information Officer. Credit for producing the colored illustrations of algae goes to Harold J. Walter, and for the cover design to Judith A. Walters. All photographs and line drawings were furnished by the writer except Figure 38 which was obtained from J. R. Baylis, Engineer of Water Purification, Bureau of Water, Chicago, Illinois. The writer is indebted to these co-workers and many others for their painstaking cooperation in preparation of the manual.

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Algae in Water Supplies

CHAPTER 1

INTRODUCTION

THE GREAT INCREASE in population and the rapid development of agriculture and industry have caused a phenomenal increase in our use of water in recent years and have brought about many difficult problems in the procurement of suitable water supplies. As the country continues to grow and develop, these problems will become more widespread and complex. In the past, most people of the United States have taken their water supply for granted, assuming that it is something which is always available. This may be due in part to our efficient water distribution systems. The present generation has become so accustomed to an abundant, safe and potable water supply at the mere turning of a tap, that its value and importance are not realized. It is certain, however, that the people of this country will increasingly recognize that suitable water supplies are exhaustible and that water costs whatever you have to pay to get it.

In the clearing and development of the country, especially the eastern portion, changes in the ground cover and the surface soil have greatly altered surface runoff and ground seepage. Deforestation, fires, overgrazing, agricultural use, and drainage have increased surface runoff and erosion and reduced soil seepage in many areas. It has been estimated by some authorities that, during the past 50 years, the water table in the eastern half of the country has been lowered about 60 feet. The lowering of the water table, coupled with increased use of ground water, has created severe shortages of ground water in many areas.

As population and industrial demands increase and ground water supplies become inadequate, more and more cities and villages are turning to lakes, streams, or reservoirs for their water supplies. This change from ground to surface source of supply has created many new problems for those engaged in the procurement and treatment of water for domestic and other uses. Ground waters are essentially free of organisms which may cause nuisance problems, whereas all surface waters contain many organisms which may complicate the provision of a potable water. Some problems are odor and taste, the clogging of filters, growths in pipes, cooling towers and on reservoir walls, surface water mats or blooms, infestations in finished waters, and toxicity.

Present methods of waste disposal are intensifying the nuisance organism problems in water supplies. The number and kinds of algae and other organisms which grow in surface waters depend on environmental conditions. Fertilizing materials such as sewage and organic wastes from milk plants, canneries, slaughter houses, paper mills, starch factories, and fish processing plants greatly increase the productivity of the waters and their crops of algae and other plankton organisms, many of which produce problems when they become abundant. It is apparent, therefore, that nuisance organism problems will become more widespread and severe as our growing urban populations and industry continue to discharge their wastes into streams.

In muddy streams such as the Missouri, turbidity limits light penetration sufficiently so that few problems occur from algal growth. When impoundments are built in such a stream they create settling basins in which the water clears and algal growths develop, producing tastes and odors or other nuisance conditions. The extensive impoundment program which has been underway for over 20 years can create many water supply problems which did not exist previously in these waters.

Pool size, shape, depth, amount of shore line, extent of shoal areas, character of the bottom, physiography and soils of the watershed, amount and rate of precipitation, sunlight, and the quality of the water are all factors influencing the growth of algae in a reservoir. A narrow deep reservoir having no shoal areas, a minimum of shore line, little wind mixing, and unproductive watershed, and soft water low in dissolved solids will have less algae than a wide, shallow, irregular reservoir located in an area of rich soil where the incoming water is rich in dissolved materials and there is complete wind mixing. In many areas the best reservoir sites have already been utilized. New reservoirs will have to be built in less favorable sites where productivity of algae will be greater. In the great plains area and in several other parts of the country, reservoir sites for water storage are usually wide and shallow and favorable for the development of plankton growths.

In view of these conditions problems due to nuisance organisms will become more widespread and of greater importance. In several areas they are now the number one problem of water works operators.

The importance of the nuisance organism problem was recognized when aquatic biological investigations were activated in the Public Health Service water research laboratories at Cincinnati. A unit was set up in 1950 to study organisms that create problems in the provision of a potable water supply and to develop methods for their control or elimination. Because tastes and odors seemed to be of outstanding importance, work on this phase of the problem has been stressed. Work has been done, however, on algicides and several other phases of the problem. Although it has been possible to secure unialgal cultures of a large number of species, the growing of algae in pure culture has been difficult. Methods have yet to be developed for the growth in pure culture of most of the algal species believed to produce odors or tastes in water supplies. Some species do not grow readily in the absence of bacteria, indicating that bacteria may produce some material needed by the algae. The addi-

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tion of vitamins and certain organic materials has provided needed nutrients in some instances.

Until recently our knowledge of taste and odor algae was circumstantial and rather loose. When odors or tastes develop in water supplies, they are commonly blamed on the most abundant forms, which may or may not be the cause. Of course, when the same alga is found in a series of taste and odor outbreaks, the circumstantial evidence becomes quite strong. However, since most forms alleged to cause odor or taste are usually reported as the genus, the information is rather loose, in that some of the genera may contain 100 or more species.

When the nuisance organism work was first undertaken at the Sanitary Engineering Center, it was considered essential to work only with species and to grow them in pure culture free from bacteria, molds, yeasts, actinomycetes, and other organisms, in order to determine definitely whether a particular alga caused a taste or odor. The development of methods for the culturing of algae required considerable time and effort. Therefore, it was decided to go beyond the determination of odor or taste production, and studies have been made to improve methods of using existing algicides and to find better or more specific materials. Specific algicides would be of considerable economic benefit, as smaller amounts of material could be used to control only undesirable forms without affecting the others. This is very important from the standpoint of fisheries management, as algae constitute much of the base of the food pyramid on which all the higher forms of aquatic life depend. Further, such a procedure gives a form of biological control. The application of very toxic materials in large dosages which kill practically all the algae is undesirable. When much of the population is destroyed, the weed species come back first, and, since there is little competition, in great abundance. If selective algicides can be discovered, their use will control the problem species, while the desirable forms can increase so that the undesirable species are less likely to come back in large numbers.

Algicidal and/or biological controls are feasible in lakes, small streams, or reservoirs where most of the water is used. They are economically unsuited to large lakes or rivers where only a portion of the water is used by the water plant. In such situations some other method of treatment must be provided in the water plant. It is believed that materials causing odor or taste are present in very small amounts. If the taste and odor materials produced by so-called nuisance organisms are known, it may be possible to treat or change them by additives to render them innocuous. This could probably be done in the coagulation process. Investigations are underway to recover, isolate, and identify odoriferous materials produced by algae and other organisms in water supplies.

Studies of attempts to control algal problems in water works have revealed hit-or-miss procedures, little coordination of effort, and only occasional systematic recording of essential data. The great majority of water works are not staffed for making studies to determine the cause of their trouble, to identify the organisms responsible, or to detect their development before the undesirable materials actually get into the water system in quantity. The value of continued surveillance of algal populations has been proven by studies in several of the larger water plants. There has been a need for some time for a planned and uniform approach to this problem, usable by more plants and placing information in an understandable and useful form into the hands of those who need it. This manual is an attempt to meet this need by water plant operators in appraisal of nuisance organism problems and furnishing information for remedying some difficulties.

It is realized that very few operators or members of their staff have had training in aquatic biology or in the identification of algae. However, if growths of algae are to be detected and controlled before they cause trouble, continued surveillance of plankton populations and identification of the organisms are essential. This manual presents a simplified key limited to species of importance in water supplies. All terms and structures used in this key are defined and illustrated. The most important species of algae are illustrated in three-dimensional drawings in color which show both external and internal structures. The drawings are based on actual specimens and on descriptions from a large number of texts. It is believed that with these drawings and the key any operator who applies himself diligently will be able to identify at least the most important forms. As experience is gained he should become able to detect the development of troublesome algae so that control measures can be initiated before real trouble develops. In addition to the key and plates, the manual deals with the ecology and life history of algae and presents concise and pertinent information on filter clogging and mat-forming algae, attached forms, algicides, and algal control.

Eventually this manual may become useful in at least two other ways in meeting important problems. If algicides specific for certain species or groups of species can be found, operators can identify the organisms causing the trouble and, from a listing of specific algicides, determine the particular material which should be used for control. Further, if the source and substance of materials produced by algae which cause odors or tastes can be identified, the operator will be helped to determine what materials and methods should be used in the water plant to render innocuous the algal metabolites causing the trouble.

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CHAPTER II

SIGNIFICANCE OF ALGAE IN WATER SUPPLIES

ALGAE are common and normal inhabitants of surface waters and are encountered in every water supply that is exposed to sunlight. While a few of the algae are found in soil and on surfaces exposed to air, the great majority of them are truly aquatic and grow submerged in the waters of ponds, lakes, reservoirs, streams, and oceans. By operators of water treatment plants the algae are best known for their ability to produce odors and tastes and to clog sand filters. In addition, they have come to be recognized as important in the water supply in many other ways, including their capacity for modifying the pH, alkalinity, color, turbidity, and lately the radioactivity of the water. Some are undoubtedly the most troublesome of the various types of nuisance organisms, but others can actually be put to good use in improving a water supply.

One of the principal reasons for the importance of algae is their alibity to give rise to very large quantities of organic matter in the water. It has been estimated, for example, that more than 130 tons of algae per day flow into Fox River, Wis., from Lake Winnebago (1). The volume of plankton algae in the Scioto River, Ohio, has reached a maximum of more than 8,000 p.p.m. (2). Algal counts for Lake Michigan at Chicago have at times been over 4,000 organisms per ml. (3), and the White River in Indiana has records of counts exceeding 100,000 algae per ml. (4). Such large quantities of algal material can always be counted on to cause serious difficulties in water treatment plants.

Small numbers of certain particular kinds of algae may also be troublesome. The diatoms *Tabellaria*, *Synedra*, and *Melosira* will almost invariably reduce the length of filter runs. The brown flagellate, *Synura*, even in small numbers, is a notorious taste and odor producer. Comparatively low concentrations of most of the algae, however, are often an asset rather than a liability in raw waters.

Unattached, visible, and sometimes extensive accumulations of algae at or near the surface of the water are designated as "blooms" or "mats" (fig. 1) or "blankets," the last two terms generally being applied when the algae are in the form of threads or filaments. Many of the algae attached to submerged rock, wood, soil, or the surface of trickling filters may form continuous carpets of growth. When the water becomes turbulent, fragments of the algal carpet may become detached and be carried away. These massive growths of algae can be troublesome in clogging screens, in the production of slime, and as a source of tastes and odors particularly if anaerobic decomposition occurs. The blooms and surface mats can be the cause for complaints by persons using the body of water for recreational purposes. They also may be one cause of fish kills by acting as a barrier to the penetration of oxygen into water under the algae. Algae that are dispersed and not in blooms or mats normally would have just the opposite effect.

The algae that collect and grow on the surface of a slow sand filter as a gelatinous slimy film may be responsible for gradually reducing the flow through the bed, but they also perform a useful service by adding oxygen to the water, which permits the bacterial decomposition of organic matter within the filter to remain aerobic. Anaerobic activities in the sand bed would tend to render the filtrate less palatable. The slimy mass of algae and other aquatic plants and animals at the surface of a slow sand filter is called the "filter skin" and has also been referred to under the German name of "Schmutzdecke."

The unattached organisms that are dispersed individually or in colonies in the water are designated collectively as the "plankton." Included are the plankton algae, which constitute most of the "phytoplankton" (meaning plant plankton), and the planktonic animals or "zooplankton." When the water supply comes from a large, deep reservoir or lake, the planktonic algae are likely to be of much more significance than the attached or "benthic" algae. Many water treatment plants, therefore, keep records of the plankton but not of the benthos. In some treatment plants it is a general practice to apply an algicide to the raw water whenever the concentration of planktonic algae approaches a count of 500 areal standard units per ml. (5).

All surface waters contain dissolved and suspended materials which serve as nutrients and support the growth not only of algae but of many other kinds of aquatic life, numbers of which are governed to a great extent by the amounts and kinds of nutrients available. Some of the aquatic plants and animals are large, such as the fish, turtles, cattails, and water lilies, but there are immense populations of small forms, many of them microscopic in size. The microscopic organisms in addition to algae include bacteria, actinomycetes, molds or fungi, yeasts, protozoa, rotifers, micro-crustacea, minute worms, and mites. Many of these may play a major part in affecting the quality of the water and have to be dealt with in the process of preparing water for domestic and industrial use. The present account deals primarily with the algae but it is obvious that the activities of one group of organisms are closely associated with activities of the other organisms present in the same environment.

PHOTOSYNTHESIS

Algae differ from the other groups of small or microscopic organisms in possessing an internal green pigment called chlorophyll, sometimes hidden or partially masked by other pigments, which enables them in the presence of sunlight to

Figure 1.—Mats of algae floating on the surface of water.

combine water and carbon dioxide to form starch or related substances, and to release oxygen into the water. This process known as photosynthesis (6) is absent in all typical bacteria, actinomycetes, fungi, yeasts, protozoa, and crustacea. In general it is not characteristic of animals but is common to all types of green plants. On the other hand, respiration is a process carried on by all plants and animals and the gaseous exchange is the opposite of that in photosynthesis; i.e., oxygen is absorbed and carbon dioxide is released. However, in algae and other green plants the rate of their photosynthesis is normally faster than their respiration. These organisms, therefore, release more oxygen than they use and absorb more carbon dioxide than they release while animals and other nonphotosynthetic organisms release carbon dioxide and absorb oxygen from their environment. For this reason, the amounts of oxygen and carbon dioxide in an environment such as water often depend to a large degree upon the relative rates of photosynthesis and respiration being carried on collectively by the algae, bacteria, and other organisms in that area.

Some aquatic, pigmented forms containing chlorophyll are able to swim or crawl, although most of the typical algae are not capable of self locomotion. Many of these pigmented swimming forms have whip-like structures called flagella and have been classified by some workers as protozoan animals rather than as algae. However, it seems best, in sanitary science, to list them as algae (7).

The algae make possible important chemical changes and metabolic activities in the water through their release of oxygen during daylight hours. The oxygen is made available for respiration that is carried on by all types of animals from fish on down to the smallest forms. It helps to prevent foul or septic conditions by stimulating the activities of aerobic rather than anaerobic bacteria. The algae constitute the primary source for continuous daytime renewal of this essential element in most bodies of quiet water. Oxygen release by algae and oxygen uptake by reaeration are the two primary sources for renewal of oxygen in flowing streams and turbulent water.

Another important chemical effect of algae is the continuous removal of carbon dioxide from the water during the daylight hours as a result of photosynthesis. This process brings about an alteration in the relative amounts of soluble (unbound) carbonic acid, intermediately soluble (half bound) bicarbonates, and the nearly insoluble (bound) monocarbonates, often causing some of the latter to precipitate. All of this produces a change in the total hardness of the water. Vigorous algal growths have been known to reduce the water hardness by as much as one-third.

These changes in carbon dioxide and hardness also tend to change the pH of the water. The pH will increase as the algae increase their photosynthetic activity during daylight hours. The pH then decreases at night when the algae are not carrying on photosynthesis but are releasing carbon dioxide in respiration. These changes in hardness and in pH must be taken into account at the water treatment plant since they may require changes in the dosages of chlorine, alum, and other chemicals added to the water at the plant .

Corrosive activity of the water is also often increased as a result of algal growth. This can have far-reaching effects on the pipes in the distribution system and on many industrial processes where water is in contact with the machinery. In California, algae attached to the metal walls of sedimentation tanks caused deep pits to be formed in the metal as a result of the depolarizing action of the oxygen produced by the algae. Algae in contact with submerged concrete blocks have caused complete disintegration of the concrete (8).

Increasing attention is now being paid to algae that produce toxic organic substances causing the death of many kinds of wild and domestic animals. However, there appear to be few records of algae that are toxic to humans, although some have several times been looked upon with suspicion as the possible cause of certain outbreaks of gastro-intestinal disorders among persons using a common water supply.

Problems introduced by algae in the providing of suitable water supplies, together with the utilization of some of these same organisms in improving the water supplies and in treatment of sewage, clearly indicate a need for more knowledge of their environmental requirements, life histories, growth, and nutrition. In order to help in meeting this need, research scientists at a number of laboratories, including the Robert A. Taft Sanitary Engineering Center of the Public Health Service in Cincinnati, are studying the various algae of importance in water and sewage.

Reports have been published for various parts of the continent which summarize the importance of algae and other interference organisms in water supplies. The regions that have been covered include New England (9), the Chesapeake area (10), Indiana (11), and Canada (12).

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CHAPTER III

IDENTIFICATION OF ALGAE

SEVERAL of the larger groups of algae are recognized by their common names, such as the diatoms, desmids, armored flagellates, euglenoids, greens, blue-greens, yellow-greens, browns, golden-browns, and reds. Included in these groups are numerous individual kinds which total probably more than twenty thousand. A few of the less specific kinds of algae have common names as well as scientific names, as for example, the names "water net" for *Hydrodictyon* (fig. 2), "green felt" for *Vaucheria*, "sea lettuce" for *Ulva*, "water silk" for *Spirogyra*, and "stone wort" for *Chara*. Each one of these is known as a genus (plural, "genera") and is composed of specific kinds known as species (plural also is "species"). For example, two species of the genus *Spirogyra* would be *Spirogyra ellipsospora* (fig. 3) and *Spirogyra varians* (fig. 4). For the great majority of algae there are only scientific names available, no common names having as yet been applied to them.

Experience in water and sewage treatment plants has demonstrated that there is considerable difficulty in recognizing the various algae that are encountered and in determining which of the many present are really important. In this manual the algae are considered and displayed according to their significance to sanitary scientists and technicians, rather than with regard to their evolutionary relationship as botanists would normally classify them. Obviously only a fraction of the total number of algae can be included, but many of those omitted are comparatively rare types or relatively unimportant in water supplies.

For convenience, most of the algae of importance in water supplies may be characterized in four general groups, the *blue-green algae*, the *green algae*, the *diatoms*, and the *pigmented flagellates*. This is a simplification of the grouping which is used in more extensive treatises on the classification of algae. As might be expected, there are a few miscellaneous forms which do not fit into these four groups. The blue-green algae include such forms as *Oscillatoria* (pls. 2 and 3), *Anacystis* (*Microcystis*) (pls. 1 and 2), and *Desmonema* (fig. 5). As the name implies, many of the specimens have a blue-green color. They are surrounded by a slimy coating. Their form and internal structure is comparatively simple. The green algae are exemplified by *Chlorella* (pls. 2 and 3), *Pediastrum* (fig. 6), and *Spirogyra* (pls. 2 and 3). Their most common color is grass green to yellow-green and is localized in plastids. Reserve food is generally starch. The desmids (fig. 7) are a subgroup of the green algae. The diatoms are represented by the genera *Cyclotella* (pls. 2 and 4) and *Navicula* (pls. 2 and 4). They have a rigid wall containing silica which is sculptured with regularly arranged markings. Their plastids are brown to greenish in color. In the pigmented flagellates are placed all of the swimming algae which have flagella. *Euglena* (pls. 3 and 5) and *Synura* (pl. 1) are representatives of this group. A comparison of the more significant characteristics of the four groups of algae is summarized in table 1.

A total of 262 species of the most important algae are included in the next six chapters of this manual, being considered according to their significance under the general titles of Taste and Odor Algae, Filter Clogging Algae, Polluted Water Algae, Clean Water Algae, Surface Water Algae (plankton and surface-mat algae), and Algae Attached to Reservoir Walls. In table 2, these algae are listed alphabetically, together with their group, the title under which they are discussed, and the plate or figure where they are illustrated. A "key" for their identification is included in the appendix. A large number of additional algae are referred to briefly in chapters X and XI but are not included in the key. More extensive manuals on both marine and fresh-water algae would be required for their identification (1, 2, 3, 4, 6, 7, 8, 10, 11, 12).

Authorities have recently changed the names of several of the better known algae. The list of these changes which involve any algae referred to in the manual is given in table 3. Most of the changes involve genera and species of blue-green algae and were reported by Drouet and Daily in 1956 (3).

Table 1.—Comparison of the Four Major Groups of Algae in Water Supplies.

Characteristics	Algal groups			
	Blue-green algae	Green algae	Diatoms	Pigmented flagellates
Color	Blue-green to brown	Green to yellow-green	Brown to light-green	Green or brown
Location of pigment	Throughout cell	In plastids	In plastids	In plastids
Starch	Absent	Present	Absent	Present or absent
Slimy coating	Present	Absent in most	Absent in most	Absent in most
Cell wall	Inseparable from slimy coating	Semirigid, smooth or with spines	Very rigid, with regular marking	Thin, thick or absent
Nucleus	Absent	Present	Present	Present
Flagellum	Absent	Absent	Absent	Present
Eye spot	Absent	Absent	Absent	Present

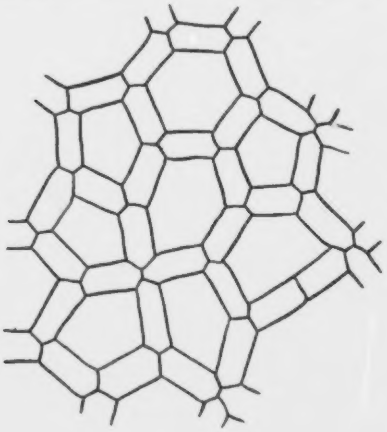

Figure 2.—Water net, *Hydrodictyon reticulatum*.

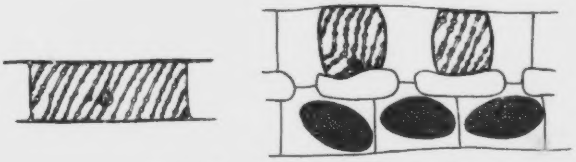

Figure 3.—*Spirogyra ellipsospora*.

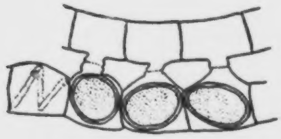

Figure 4.—*Spirogyra varians*.

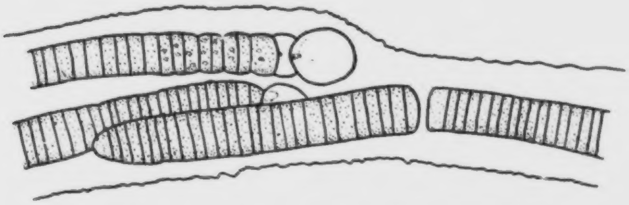

Figure 5.—A blue-green alga, *Desmonema wrangelii*.

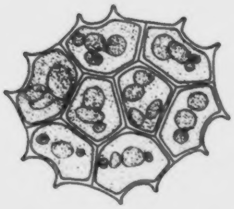

Figure 6.—A green alga, *Pediastrum boryanum*.

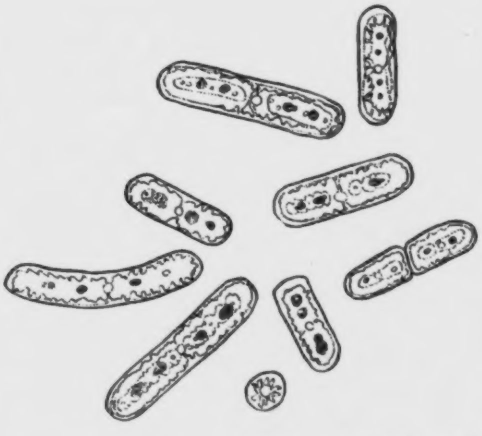

Figure 7.—A desmid, *Cylindrocystis brebissonii*.

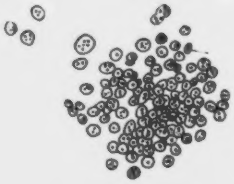

Figure 8.—*Anacystis cyanea* (formerly *Microcystis aeruginosa*).

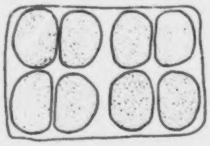

Figure 9.—*Agmenellum quadriduplicatum* (formerly *Merismopedia glauca*).

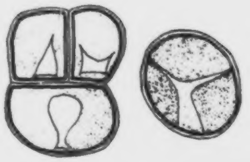

Figure 10.—*Phytoconis botryoides* (formerly *Protococcus viridis*).

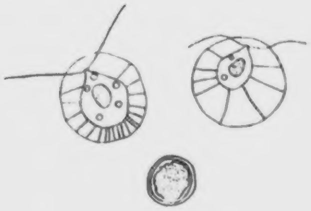

Figure 11.—*Haematococcus lacustris* (formerly *Sphaerella lacustris*).

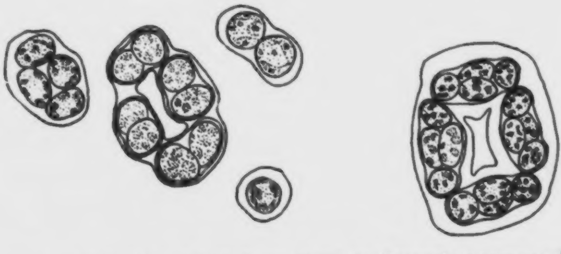

Figure 12.—Colonies of indefinite form in *Oocystis novae-semliae*.

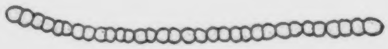

Figure 13.—A simple filament, *Anabaena constricta*.

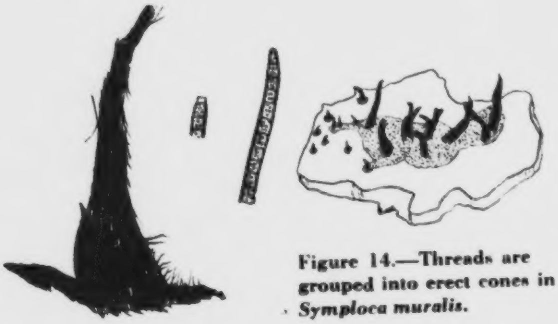

Figure 14.—Threads are grouped into erect cones in *Symploca muralis*.

For example, *Microcystis* (fig. 8) is changed to *Anacystis*, *Coelosphaerium* is included under *Gomphosphaeria*, and *Merismopedia* (fig. 9) becomes *Agmenellum*. The name of the green alga *Protococcus* (fig 10) is changed to *Phytoconis* (9). The pigmented flagellate *Sphaerella* (fig. 11) is now recognized as *Haematococcus* (1).

Six plates of illustrations in color together with photographs, line drawings, the key, and descriptions are included for use as aids in the identification of the significant forms. The six color-plates of important algae are the work of artist-biologist Harold J. Walter, and were done under the supervision of the author (13, 14). The original paintings are on display at the Robert A. Taft Sanitary Engineering Center, in Cincinnati, Ohio. The line drawings which are included as figures throughout the manual were made by the writer and published previously in two taxonomic papers (15, 16).

The six plates of algae in color represent three general areas of concern for plant operators, namely, water treatment, sewage treatment, and water reservoirs. Taste, odor, and filter clogging are the most troublesome problems faced by many operators in water treatment plants. Representative algae associated with these conditions are illustrated on plates 1 and 2. In connection with water pollution, natural stream purification, and sewage treatment, the significant algae are those whose growth or survival is closely related to the amount and composition of sewage and other organic wastes in the water. Plates 3 and 4 illustrate the contrasting groups of polluted water and clean water algae. Finally, in the reservoirs and settling basins of water supply systems are encountered the drifting, swimming, and attached growths of algae which can become troublesome in the raw water and can cause nuisance conditions in the treatment plant. Plates 5 and 6 illustrate respectively the planktonic and mat-forming algae of surface waters and the algae attached to the sides of reservoirs and settling basins.

The algae as illustrated on the plates are not shown in actual or relative size. Some of the forms illustrated are so minute as to be visible only under very high magnification of a compound microscope. Other forms are large enough to be seen under lower magnification or even with the unaided eye. *Chlorella* on plates 2 and 3, and *Chrysococcus* on plate 4 are good examples of minute, microscopic algae while *Lemanea* on plate 4, and *Chara* on plate 6 are large forms often growing to a length of several inches. Thus, rather than having the drawing scale the same for all of the algae, each is enlarged sufficiently to make clear its own particular characteristics. The magnification for each drawing is given with the species name in the list accompanying each plate.

The six color plates contain illustrations of 129 of the algae referred to in this manual. Drawings and photomicrographs of some other forms are also included in the manual as noted earlier. The paintings and the drawings were prepared in such a way as to emphasize the characteristics most helpful in the identification of unstained material in water samples.

While illustrations may be a real aid in recognizing the various kinds of algae, an identification "key" is essential for distinguishing the many genera and species encountered. An original key, limited to the 262 algae selected as most important in water supplies, has therefore been prepared for this manual. Since many other algae may be associated with these forms in the water, the supplementary use of additional treatises on algae would help to assure greater accuracy in identifying the specimens.

When acquainted with the nature of an identification "key", an observer can make direct use of the device in determining the name of a particular form whose essential characteristics have been determined through study under a microscope. It is necessary, therefore, to know what are these "essential characteristics" that must be observed in any specimen before the key is used for its identification. The essential characteristics are considered under the following headings: 1, gross structure of the alga, including shape, size, and cell grouping; 2, cell structure; 3, specialized parts of cells; 4, specialized parts of multicellular algae; and 5, measurements.

GROSS STRUCTURE

The cells of algae may be isolated units so that each "unicell" behaves as an independent organism. Hundreds of genera of algae are unicellular. Examples illustrated include *Tetraedron*, *Euglena*, and *Gomphonema* on plate 3. In many other algae the cells are grouped together into various shapes of colonies such as are illustrated by *Asterionella*, *Hydrodictyon*, *Anacystis* (*Microcystis*), *Dinobryon*, *Volvox*, *Pandorina*, and *Synura* on plate 1 and *Oocystis* in figure 12. The colony of cells may have a definite, distinct shape, as in *Volvox*, or it may be indefinite and irregular, as in *Anacystis*. Colonies in the form of threads (filaments) where the cells are arranged in a simple linear series or chain are distinctive and very common (fig. 13). The threads may be isolated, or obviously grouped together as in *Symploca* (fig. 14); they may be unbranched (simple) or branched. The branches may be attached to the primary thread singly (alternate), in pairs (opposite), or more than two together (whorled). *Anabaena*, *Spirogyra*, *Oscillatoria*, and *Arthrospira*, on plate 3 are simple filaments. *Microthamnion* (fig. 15) and *Audouinella* (pl. 6) have alternate branching; *Stigeoclonium* (pl. 6) has, in part, opposite branching; and *Chara* (pl. 6) has whorled branching. *Chaetophora* and *Phormidium* on plate 6 have filaments grouped together into larger growths.

In a few cases the alga may be in the form of a continuous, sometimes branching "tube" with no cell walls to divide the material into distinct units or cells. The tube is described as being "nonseptate" (having no transverse walls). *Botrydium* (fig. 16) and *Vaucheria* on plate 6 have this type of structure. In others, such as *Hydrurus* (fig. 17) and *Tetraspora* on plate 6 the whole gelatinous mass, in which numerous cells are embeded, is tubular in form.

A few fresh-water algae have cells forming dense massive "strands," the strand being from a few to many cells thick and with central and marginal (peripheral) cells different

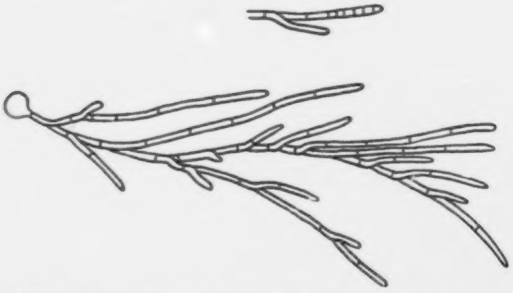

Figure 15.—Filament with alternate branching in *Microthamnion strictissimum*.

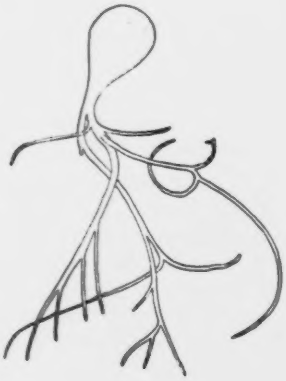

Figure 16.—A branching, tubular, nonseptate alga, *Botrydium granulatum*.

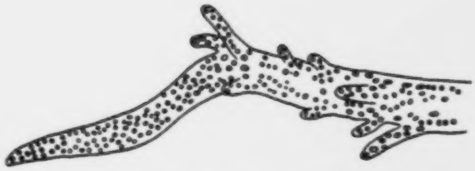

Figure 17.—Cells embedded in a gelatinous tube in *Hydrurus foetidus*.

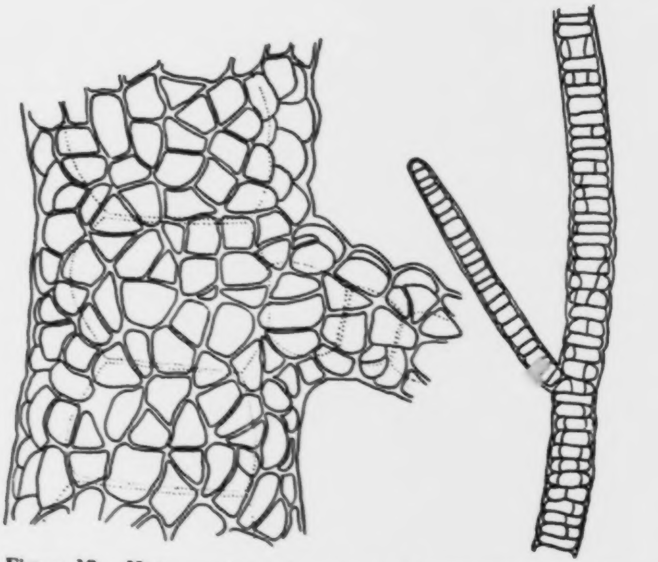

Figure 18.—Mature and young portions of *Compsopogon coeruleus*.

from one another. *Lemanea* on plate 4 and *Compsopogon* on plate 6 and in figure 18 are examples of specialized strands. Finally, a limited number of algae have cells arranged to form a flat or bent "membrane," as indicated by *Hildenbrandia* on plate 4.

In summary, the gross structural forms encountered among the algae include the unicell, colony, filament, tube, strand, and membrane.

CELL STRUCTURE

The three main parts of many algal cells are the protoplast, the cell wall, and the outer matrix. Within the protoplast may be the one or more separate bodies colored green, yellow-green, brown, or some other color, and known as "plastids" or "chromatophores." In the blue-green algae (Myxophyceae) the pigments are not localized in plastids but are distributed throughout the whole protoplast. Some of the protoplasts may contain bodies other than plastids, such as nuclei, crystals, starch grains, oil droplets, cell sap "vacuoles," and spherical "pyrenoids" around which minute grains of starch collect. Pyrenoids are generally inside of the plastids, as shown in *Chlorella* on plate 2 and *Oocystis* and *Scenedesmus* on plate 5. The nucleus of the cell is present in all but the blue-green algae, but is seldom referred to in this manual because it is colorless and difficult to observe without staining or other special treatment of the material.

The cell wall of algal cells is commonly a thin, rigid membrane which is in contact with the outer edge of the protoplast and completely surrounds it. Some of the swimming algae, such as *Euglena* on plate 5, do not have a rigid wall and their protoplasts are therefore somewhat flexible, making them changeable in form. In the green algae the cell wall is semirigid and composed of cellulose. In diatoms the wall is very rigid and composed principally of silica that is sculptured with a regular, even pattern of lines and dots as illustrated by *Diatoma* and *Navicula* on plate 2.

The outer matrix, when present, tends in most cases to be a flexible, colorless, gelatinous material which has been secreted through the cell wall. It often changes with age to become pigmented, to show stratification, and to develop a semirigid surface membrane. In most cases it assumes a form and structure characteristic for the particular alga of which it is a part. In *Botryococcus* (pl. 5), its brown color partially hides the green plastids within the protoplasts. In *Gonium* (pl. 5) it holds the cells in a flat plate, while in *Sphaerocystis* (pl. 5) it forms a sphere. *Dinobryon* and *Trachelomonas* on plate 2 have a specialized outer matrix called a "lorica" which is rigid and of definite form. *Lyngbya* and *Tolypothrix* on plate 6 and *Microcoleus* (fig. 19) have an outer matrix in the form of a semirigid tube-like "sheath."

SPECIALIZED PARTS OF CELLS

Certain additional cell parts may be characteristics useful in identification. Some cells have a gelatinous "stalk," one end of which is attached to the cell and the other to some other object. *Gomphonema* and *Achnanthes* on plate 6 are

Table 2.—Algae in Water Supplies

A List of the More Important Species

Key to Columns:
1. Alga name.
2. *Group:* D, diatom; G, green; BG, blue-green; R, red; Fl, flagellate; De, desmid; YG, yellow-green.
3. *Significance:* A, attached; S, surface; F, filter; C, clean; P, polluted; T, taste and odor.
4. Plate number or figure number (bold face), if illustrated.

1	2	3	4
Achnanthes: microcephala	D	A	6
Actinastrum:			
gracillimum	G	S	5
hantzschii	G	S	
Agmenellum:			
quadriduplicatum:			
glauca type	BG	C	4
tenuissima type	BG	P	3
Amphora: ovalis	D	C	
Anabaena:			
circinalis	BG	T	
constricta	BG	P	3 **12**
flos-aquae	BG	F	2
planctonica	BG	T	1
Anacystis:			
cyanea	BG	T	1 **7**
dimidiata	BG	F	2
montana	BG	P	3
thermalis	BG	S	
Ankistrodesmus:			
falcatus	G	S	**34**
var. acicularis	G	C	4
Aphanizomenon: flos-aquae	BG	T	1
Arthrospira: jenneri	BG	P	3 **38**
Asterionella:			
formosa	D	F	2
gracillima	D	T	1
Audouinella: violacea	R	A	6 **24**
Batrachospermum:			
moniliforme	R	A	6
vagum	R	C	
Botryococcus: braunii	G	S	5
Bulbochaete:			
insignis	G	A	6
mirabilis	G	C	
Calothrix:			
braunii	BG	A	
parietina	BG	C	4 **33**
Carteria: multifilis	Fl	P	3
Ceratium: hirundinella	Fl	T	1
Chaetopeltis: megalocystis	G	C	
Chaetophora:			
attenuata	G	A	
elegans	G	A	6
Chara:			
globularis	G	A	6
vulgaris	G	T	
Chlamydomonas:			
globosa	Fl	T	
reinhardi	Fl	P	3
Chlorella:			
ellipsoidea	G	S	
pyrenoidosa	G	F,P	2
vulgaris	G	P	3
Chlorococcum: humicola	G	P	3
Chlorogonium: euchlorum	Fl	P	3 **52**
Chromulina: rosanoffi	Fl	C	4
Chroomonas:			
nordstetii	Fl	C	
setoniensis	Fl	C	
Chrysococcus:			
major	Fl	C	
ovalis	Fl	C	
rufescens	Fl	C	4
Chrysosphaerella: longispina	Fl	T	
Cladophora:			
aegagropila	G	F	
crispata	G	A	6
fracta	G	S	
glomerata	G	A,C	4
insignis	G	T	
Closterium:			
aciculare	De	S	
moniliferum	De	F	2
Coccochloris: stagnina	BG	C	4
Cocconeis:			
pediculus	D	A	
placentula	D	C	4
Coelastrum: microporum	G	S	5
Compsopogon: coeruleus	R	A	6 **17**
Cosmarium:			
botrytis	De	S	
portianum	De	T	
Crucigenia: quadrata	G	S	
Cryptoglena: pigra	Fl	P	
Cryptomonas: erosa	Fl	T	**38**
Cyclotella:			
bodanica	D	C	4
compta	D	T	
glomerata	D	S	
meneghiniana	D	F	2
Cylindrospermum:			
muscicola	BG	T	
stagnale	BG	S	5
Cymatopleura: solea	D	S	
Cybella:			
cesati	D	C	
prostrata	D	A	6
ventricosa	D	F	2
Desmidium: grevillii	De	S	5
Diatoma: vulgare	D	F,T	2
Dichotomosiphon: tuberosus	G	F	
Dictyosphaerium:			
ehrenbergianum	G	T	
pulchellum	G	F	
Dimorphococcus: lunatus	G	S	
Dinobryon:			
divergens	Fl	T	1
sertularia	Fl	F	2
sociale	Fl	S	
stipitatum	Fl	C	
Draparnaldia:			
glomerata	G	A	6
plumosa	G	C	
Entophysalis: lemaniae	BG	C	4
Epithemia: turgida	D	A	
Euastrum: oblongum	De	C,S	5
Eudorina: elegans	Fl	S	5
Euglena:			
agilis	Fl	P	
deses	Fl	P	
ehrenbergii	Fl	C	
gracilis	Fl	P,S	5
oxyuris	Fl	P	
polymorpha	Fl	P	
sanguinea	Fl	T	
spirogyra	Fl	C	
viridis	Fl	P	3 **38**
Fragilaria:			
capucina	D	S	5
construens	D	T	
crotonensis	D	F	2
Glenodinium: palustre	Fl	T	
Gloeococcus: schroeteri	G	C	
Gloeocystis:			
gigas	G	A	
planctonica	G	T	
Gloeotrichia:			
echinulata	BG	F	
natans	BG	S	**37**
Gomphonema:			
geminatum	D	A	6
olivaceum	D	A	
parvulum	D	P	3

1	2	3	4
Gomphosphaeria:			
aponina	BG	S	5
lacustris:			
collinsii type	BG	S	
kuetzingianum type	BG	T	1
wichurae	BG	S	
Gonium: pectorale	Fl	S	5
Gyrosigma: attenuatum	D	S	
Hantzschia: amphioxys	D	P	
Hildenbrandia: rivularis	R	C	4
Hyalotheca: mucosa	De	S	
Hydrodictyon: reticulatum	G	F,T	1 **2**
Kirchneriella: lunaris	G	S	
Lemanea: annulata	R	C	4
Lepocinclis:			
ovum	Fl	P	
texta	Fl	P	3
Lyngbya:			
digueti	BG	P	3
lagerheimii	BG	A	6
ocracea	BG	A	
versicolor	BG	S	
Mallomonas: caudata	Fl	C,T	1 **38**
Melosira:			
crenulata	D	S	
granulata	D	F	2
varians	D	F,P	
Meridion: circulare	D	C	4
Micractinium: pusillum	G	S	5
Micrasterias: truncata	De	C	4
Microcoleus: subtorulosus	BG	C	4
Microspora: amoena	G	A	6
Mougeotia:			
genuflexa	G	S	
scalaris	G	S	5
sphaerocarpa	G	F	
Navicula:			
cryptocephala	D	P	
exigua var. capitata	D	C	
gracilis	D	C	4
graciloides	D	F	2
lanceolata	D	F	
radiosa	D	S	
Nitella:			
flexilis	G	A	
gracilis	G	T	1
Nitzschia:			
acicularis	D	P	
linearis	D	C	
palea	D	F,P	3
Nodularia: spumigena	BG	S	5 **47**
Nostoc:			
carneum	BG	S	
pruniforme	BG	A	
Oedogonium:			
boscii	G	A	
grande	G	A	
idioandrosporum	G	S	
suecicum	G	A	6
Oocystis: borgei	G	S	5
Ophiocytium: capitatum	G	S	
Oscillatoria:			
agardhii	BG	S	
amphibia	BG	F	
chalybea	BG	F,P	2
chlorina	BG	F,P	3
curviceps	BG	T	
formosa	BG	P	
lauterbornii	BG	P	3
limosa	BG	P	**29**
ornata	BG	F	
princeps	BG	F,P	2 **31**
pseudogeminata	BG	F	
putrida	BG	F	3
rubescens	BG	F	
splendida	BG	F	2
tenuis	BG	A,P	**30**
Palmella: mucosa	G	A,F	2
Pandorina: morum	Fl	P,T	1
Pediastrum:			
boryanum	G	S	5 **4**
duplex	G	S	**51**
tetras	G	T	
Peridinium:			
cinctum	Fl	T	1
wisconsinense	Fl	F	
Phacotus: lenticularis	Fl	C	4
Phacus:			
longicauda	Fl	C	
pleuronectes	Fl	S	5
pyrum	Fl	P	3
Phormidium:			
autumnale	BG	P	3
inundatum	BG	C	
retzii	BG	A,S	
uncinatum	BG	A,P	6 **32**
Phytoconis: botryoides	G	A	6 **9**
Pinnularia:			
nobilis	D	C	4
subcapitata	D	C	
Pithophora: oedogonia	G	A	**41**
Plectonema: tomasiniana	BG	S	
Pyrobotrys:			
gracilis	Fl	P	
stellata	Fl	P	3
Rhizoclonium: hieroglyphicum	G	C,A	4 **38**
Rhizosolenia: gracilis	D	S	
Rhodomonas: lacustris	Fl	C	4
Rhoicosphenia: curvata	D	A	
Rhopalodia: gibba	D	S	
Rivularia:			
dura	BG	F	2
haematites	BG	T	
Scenedesmus:			
abundans	G	T	
bijuga	G	S	
dimorphus	G	S	
quadricauda	G	P,S	5 **19**
Schizomeris: leibleinii	G	A	**42**
Schroederia: setigera	G	S	
Scytonema: tolypothricoides	BG	S	
Selenastrum: gracile	G	S	
Sphaerocystis: schroeteri	G	S	5
Spirogyra:			
communis	G	P	3
fluviatilis	G	S	
majuscula	G	T	
porticalis	G	F	2
varians	G	S	**36**
Spirulina: nordstedtii	BG	S	
Spondylomorum: quaternarium	Fl	P	
Staurastrum:			
paradoxum	De	T	1
polymorphum	De	S	
punctulatum	De	C	4
Stauroneis: phoenicenteron	D	S	5
Stephanodiscus:			
binderanus	D	F	
hantzschii	D	F,S	5
niagarae	D	T	
Stichococcus: bacillaris	G	P	
Stigeoclonium:			
lubricum	G	A	6
stagnatile	G	S	
tenue	G	P	3
Stigonema: minutum	BG	A	
Surirella:			
ovata	D	P	
splendida	D	C	4 **38**
Synedra:			
acus	D	F	2
var. angustissima	D	C	
var. radians	D	F	
capitata	D	S	
pulchella	D	F	
ulna	D	T	1

Table 2—Continued

1	2	3	4
Synura: uvella	Fl	T	1 38
Tabellaria:			
fenestrata	D	F,T	1
flocculosa	D	F	2
Tetraedron: muticum	G	P	3
Tetraspora: gelatinosa	G	A	6
Tolypothrix: tenuis	BG	A	6
Trachelomonas: crebea	Fl	F	2
Tribonema:			
bombycinum	YG	F	2
minus	YG	S	
Ulothrix:			
aequalis	G	C	4
tenerrima	G	S	
variabilis	G	F	
zonata	G	A	6 28
Uroglenopsis: americana	Fl	T	1
Vaucheria:			
geminata	G	A,C	39
sessilis	G	A	6 40
Volvox: aureus	Fl	T	1
Zygnema:			
insigne	G	F	
pectinatum	G	S	
sterile	G	S	5

Table 3.—Recent Changes in Names of Algae

Old name	New name
Aphanocapsa	Anacystis.
Aphanothece	Coccochloris.
Chamaesiphon	Entophysalis.
Chamaesiphon incrustans	Entophysalis lemaniae.
Chantransia	Audouinella.
Chara fragilis	Chara globularis.
Chlamydobotrys	Pyrobotrys.
Chroococcus	Anacystis.
Chroococcus limneticus	Anacystis thermalis.
Chroococcus turgidus	Anacystis dimidiata.
Clathrocystis	Anacystis.
Coelosphaerium	Gomphosphaeria.
Coelosphaerium kuetzingianum	Gomphosphaeria lacustris.
Coelosphaerium naegelianum	Gomphosphaeria wichurae.
Encyonema	Cymbella.
Encyonema paradoxum	Cymbella prostrata.
Euglena pisciformis	Euglena agilis.
Gloeocapsa	Anacystis.
Gloeocapsa conglomerata	Anacystis montana.
Gloeothece	Coccochloris.
Gloeothece linearis	Coccochloris peniocystis.
Gomphosphaeria naegeliana	Gomphosphaeria wichurae
Holopedium	Microcrosis.
Merismopedia	Agmenellum.
Merismopedia glauca	Agmenellum quadriduplicatum.
Merismopedia tenuissima	Agmenellum quadriduplicatum.
Microcystis	Anacystis.
Microcystis aeruginosa	Anacystis cyanea.
Odontidium	Diatoma.
Oedogonium crassiusculum var. idioandrosporum.	Oedogonium idioandrosporum.
Polycystis	Anacystis.
Polycystis aeruginosa	Anacystis cyanea.
Protococcus	Phytoconis.
Protococcus viridis	Phytoconis botryoides.
Sphaerella	Haematococcus.
Spirulina jenneri	Arthrospira jenneri.
Synechococcus	Coccochloris.
Synedra delicatissima	Synedra acus var. radians.

shown with stalks. In many cases the cell may become detached from the stalk very readily. *Gomphonema* on plate 3 is illustrated without the stalk although it is originally present in this genus.

Knobs or spines may be found extending from the cell wall, or the cells may have sharp spine-like ends. *Micractinium* on plate 5 has true spines while *Ankistrodesmus* on plate 4 and *Scenedesmus* (fig. 20) have spine-like tips. Knob-like swellings on the cell wall are shown on the large cell of *Chlorococcum* on plate 3.

Swimming (motile) cells often are supplied with one, two, or occasionally more than two flexible, whip-like hairs known as "flagella," extending from the front (anterior), side (lateral), or back (posterior) of the algal cell. Lateral flagella are found in *Merotrichia* (fig. 21) while anterior flagella are shown in *Pleodorina* (fig. 22), and in two views of Gonium (fig. 23). A reduction in the illumination of the microscope field may help in making the flagella (singular, "flagellum") visible. Swimming cells also may contain a single small red or orange body called an "eye spot" in the protoplast. This eye spot is generally located near the anterior end. *Carteria* and six other motile algae are illustrated on plate 3.

Several special terms are required in the description of a diatom cell. The wall (frustule) of the diatom is composed of two approximately equal halves, the one, like a cover (epitheca), fitting with its edge over the edge of the other (hypotheca). When the cell is lying in the microscope field so that these overlapping edges are visible, the diatom is presenting its "girdle" view. If the cell is lying so that the top of the epitheca or bottom of the hypotheca is visible, the diatom is presenting a "valve" view. In *Gomphonema* on plate 6 the left hand cell is in girdle view and the right hand cell is in valve view. These views are shown together in *Gomphonema* on plate 3. When diatom cells are fastened together into a filament or ribbon, it is the valve surfaces which are attached together, so that the diatoms in the colony are always seen in their girdle view. Thus, the two attached cells in *Diatoma* on plate 2 present the girdle view while the isolated cell to the left is shown in valve view.

In diatoms the wall markings and partial partitions, particularly those visible in the valve view, are important in identification. The many fine lines or lines of dots (punctae) extending from the edge of the valve toward the center are known as "striae," or, when thicker, as "costae." There may also be a longitudinal line called a "raphe" or "true raphe," extending from one end of the cell to the other, but broken in the middle. If there is merely a clear space with no striae crossing it, rather than a longitudinal line, the space is known as a "false raphe" or "pseudoraphe." Motile diatoms generally have a true raphe which is apparently associated with their ability to swim or crawl. Partial wall-like partitions are called "septa" and extend lengthwise or crosswise into the protoplast. They appear as coarser lines than the striae. On plate 4, *Navicula* shows striae composed of punctae while *Pinnularia* has costae. Both diatoms have a true raphe. In *Diatoma* and *Synedra* on plate 2, a pseudoraphe is present. The former also has transverse septa. Longitudinal septa are seen in the girdle view of *Tabellaria* on plate 2.

There are two major groups of diatoms, those circular in valve view, with radiating striae, and those elongate in valve view, with striae that tend to be transverse. The former are known as the "centric" diatoms, and the latter as the "pennate" diatoms. On plate 2, *Cyclotella* and *Melosira* are centric in form while *Navicula* and *Cymbella* are of the pennate type.

SPECIALIZED PARTS OF MULTICELLULAR ALGAE

The shape of the end of a filament is an important diagnostic character. The end cells may be essentially the same as other cells of the filament or there may be either a gradual or an abrupt decrease in width (attenuation) to a point or even to a long spine or hair. On plate 6, *Cladophora* and *Lyngbya* have terminal cells essentially like other cells in the filaments while *Stigeoclonium* shows gradual, and *Bulbochaete*, abrupt attenuation. Some of the filaments of blue-green algae have terminal cells which are swollen (capitate) or are covered with a thick cap-like or conical membrane (calyptra). These are present in *Oscillatoria* on plate 2 and *Phormidium* on plate 6.

Some multicellular blue-green algae also have occasional special cells associated with the normal ones. One type, the "heterocyst," generally is swollen, has a clear, colorless protoplast, and a thick wall with a knob-like thickening on the inside of the wall at the place or places where the cell is connected to the adjacent cell or cells. Heterocysts are shown in *Anabaena* and *Aphanizomenon* on plate 1. Another specialized cell, the resting spore (akinete), is swollen, has a dense, granular protoplast and a thick wall. It is illustrated in *Anabaena* on plate 1 and *Cylindrospermum* and *Nodularia* on plate 5.

There are a number of other specialized cells which may be encountered in some of the algae but these are too varied or too infrequent to be dealt with here in detail. Many are reproductive cells (figs. 24, 25, 26, 27). In some forms the sexual reproductive cells must be present before identification of particular species can be made. These structures are well described in other references (1, 2).

A peculiar type of branching of filaments found in certain blue-green algae may need to be explained. It is called "false branching," and is formed when a thread of cells splits crosswise. One or both segments break through the surrounding sheath at this point and a portion moves out to the side of the original thread, thus giving the appearance of branching. False branching is evident in *Tolypothrix* on plate 6, while normal or true branching is shown in *Audouinella* and *Chaetophora* on plate 6 and of a blue-green alga in *Nostochopsis* (fig. 28).

MEASUREMENTS

There are some instances where it is necessary to know the diameter or the length and width of the algal body (thallus) or of the individual cells before species belonging to the same genus can be distinguished. The unit of measurement is the micron, designated by the Greek letter "μ". It is one one-thousandth of a millimeter or approximately one twenty-five-thousandth of an inch. A linear scale on a glass disc (ocular micrometer) which can be placed on the interior shelf (diaphragm) of a microscope eye piece (ocular) can be calibrated in microns with the aid of a stage micrometer. The ocular micrometer can then be used to obtain measurements of algae. A Whipple micrometer, used in plankton counting, can also be calibrated in microns and thus serve in a similar manner.

TYPICAL DESCRIPTIONS OF ALGAE

A few examples of descriptions of algae adequate for their identification are given below as an indication of the information which would need to be obtained by microscopic observation before attempting to determine the genus and species name of the specimen.

Example No. 1: See *Chlorella* on plate 2. Unicellular or in loose irregular colonies; cell spherical; no outer matrix; no projections or markings on the wall; protoplast with one cup-shaped green plastid filling most of the cell; one prominent pyrenoid in side or base of plastid; no great variation in size of cells; diameter of cells 3–5 microns.

Example No. 2: See *Phormidium* on plate 6. Short cylindrical cells in simple filaments which are aggregated to form a mat, with formless gelatinous matrix between them. Ends of filaments rather abruptly attenuate, bent, capitate, and with a conical calyptra. Protoplasts homogeneous, blue-green throughout, no plastids; no heterocysts nor akinetes.

Example No. 3: See *Fragilaria* on plate 5. Numerous cells united side by side into a ribbon. Contact of adjacent cells is continuous from one end of cell to the other. Cells with fine transverse striations in the wall but absent in a wide band across the center. Pseudoraphe present; septa absent. Valve view narrowly elliptical but with sides parallel much of the way; ends capitate. Girdle view rectangular, protoplast with two brown linear plastids, one on each side. Cell length, 25–100 microns.

Example No. 4: See *Chrysococcus* on plate 4. Unicellular; protoplast with two brown lateral plastids and anterior red eye spot. Protoplast surrounded by a brown spherical lorica with internal swelling at posterior end and an opening surrounded by a thickened ring at anterior end through which extends one flagellum that is about twice as long as the lorica. Cell very small, diameter of lorica 6 microns.

USE OF "KEY" FOR IDENTIFICATION OF ALGAE

In order to use the key, first observe the specimen and determine its "essential characteristics." Referring to the key, lines "1a" and "1b" at the beginning of the key are then compared with one another and with the "essential characteristics" of the specimen. At the end of the line which agrees with the specimen is a number. Turn to the place in the key where this same number is listed on the left hand side of the page and is divided into lines "a" and "b". Re-

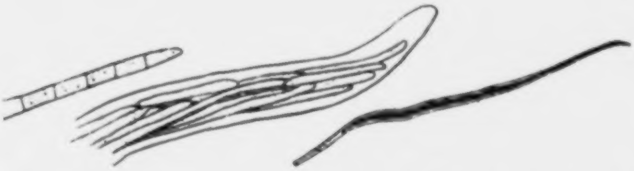

Figure 19.—*Microcoleus paludosus*, showing a single thread and a group of threads surrounded by a sheath, under high and low magnification.

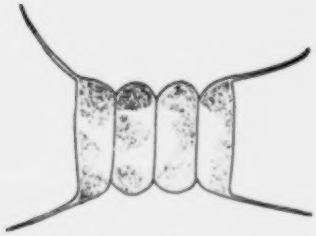

Figure 20.—*Scenedesmus quadricauda*, showing spine-like extensions on the terminal cells.

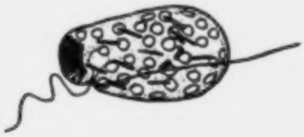

Figure 21.—Lateral flagella in *Merotrichia capitata*.

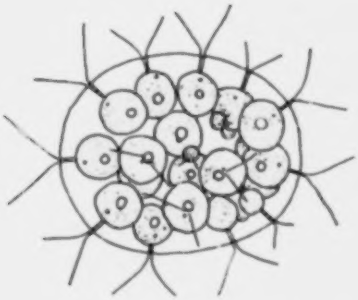

Figure 22.—Anterior flagella on cells of *Pleodorina illinoisensis*.

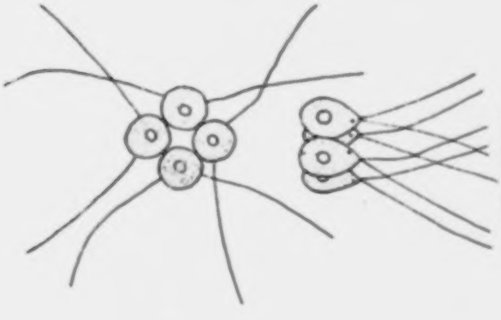

Figure 23.—Posterior and lateral views of anterior flagella on *Gonium sociale*.

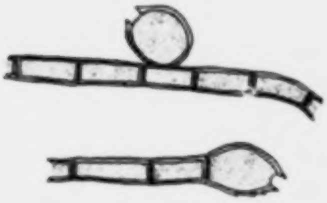

Figure 24.—Two spore-producing cells on filaments of *Trentepohlia aurea*.

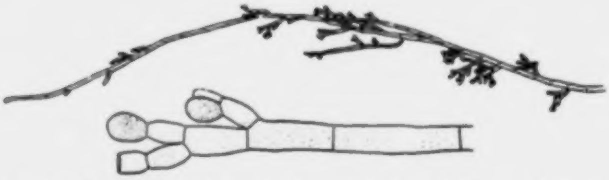

Figure 25.—Enlarged terminal reproductive cells on filaments of *Audouinella violacea*.

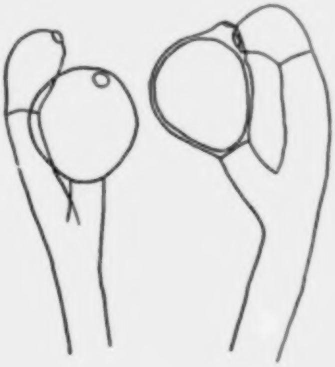

Figure 26.—Terminal cells specialized for sexual reproduction in *Vaucheria arechavaletae*.

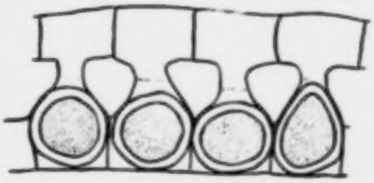

Figure 27.—Thick walled zygospores formed during sexual reproduction in *Zygnema normani*.

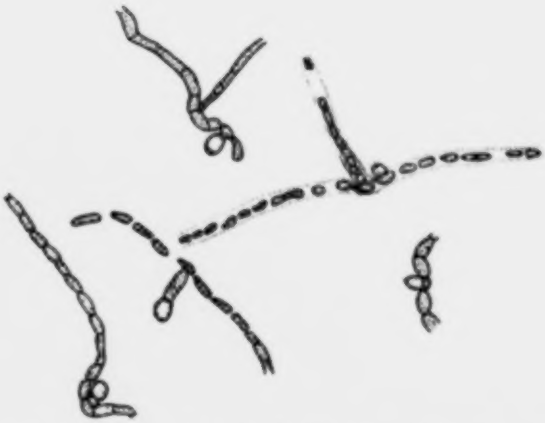

Figure 28.—True branching in the blue-green alga, *Nostochopsis lobatus*.

peat the above process and continue until a name for the alga rather than an additional number is given at the end of the line. Thus, in determining a name for "Example No. 1," above, the following lines from the key are selected, until line 283b is reached giving the species name for the alga: 1b, 123b, 173b, 184b, 185b, 225b, 230b, 232b, 276a, 277b, 279b, 280a, 281b, 282a, 283b (*Chlorella pyrenoidosa*).

When a name has been reached in the key, reference can then be made to illustrations and descriptions of that particular genus or species in this and other manuals to determine whether the specimen seen under the microscope is correctly identified. Three recent manuals on algae in water supplies have been published abroad, one in Danish (17), one in Japanese (18), and one in German (19).

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CHAPTER IV

TASTE AND ODOR ALGAE

ONE of the requirements in the production of potable water for modern communities is that the product shall be free of obnoxious and abnormal tastes and odors. Of the several causes of these tastes and odors, the algae present in the raw water supply are recognized as being either the primary, or at least one of the most important. A comprehensive study has been made of algae of the central Missouri River (1). In addition, the time of occurrence of tastes and odors was recorded at the treatment plants of cities and towns in that area, using the Missouri River as their source of water. It was found that practically all of the taste and odor occurrences were associated with the presence of algal blooms and that the few exceptional cases came during declines of dense algal growths. It is evident that, for the central Missouri River area as well as for many other parts of the country, algae are involved, either directly or indirectly, in the establishment of conditions leading to taste and odor production in water supplies.

A nationwide survey reported in 1957 (2) indicated that algae were considered by water works officials to be the most frequent causes of tastes and odors in water supplies, with decaying vegetation second in importance. The decay or decomposition is brought about by fungi and bacteria, including the actinomycetes. Often a considerable proportion of the decaying vegetation is composed of dead algal cells. The odors that are produced through the activities of fungi and bacteria may be either from the intermediate products formed during the decomposition or from special substances that are synthesized within the cells of the microorganisms. The latter appears to be true in the case of actinomycetes.

A few algae are well known for the production of specific distinctive tastes and odors while a larger number of others are associated with tastes and odors that vary in type according to local conditions. Certain diatoms, blue-green algae, and pigmented flagellates are the principal offenders but green algae, including desmids, may also be involved. Thirty-nine species have been selected as representative of the more important taste and odor algae. They are listed alphabetically under their respective groups in table 4, and eighteen of these are illustrated in color on plate 1. Other genera and species, in addition to the ones selected, must be considered also as potential offenders and many of these are included in table 5. Most of the reports dealing with specific instances where algae are regarded as the cause of taste and odor, do not give the species names of the particular forms involved. In the following discussion of this problem, therefore, reference is made to the genera rather than the species of algae.

TYPICAL ODORS FROM ALGAE

Some of the algae produce an "aromatic" odor which is described more specifically for certain organisms as that resembling a particular flower or vegetable. Common examples of these would be geranium, nasturtium, violet, muskmelon, and cucumber. In some cases it is described as an attractive spicy odor, but in others it may be very objectionable, as for example, a skunk or garlic odor. Some pigmented flagellates and diatoms produce the aromatic odors when these organisms are present in small numbers in the water.

A second type of odor, the "fishy" odor, is produced often by the same algae that are responsible for the aromatic odors. The organisms generally are present in much larger numbers when the fishy odor is evident. More specific terms that have been used to describe the fishy odors of various algae are clam-shell, cod-liver oil, sea weed, Irish moss, rockweed, and salt marsh. The differences between these are probably insignificant in water supply studies.

A third type of odor is the somewhat aromatic one which is described as "grassy." It is the most common one produced by green algae and generally is apparent only when the organisms are present in large numbers. It is reported also for certain blue-green algae and occasionally for diatoms and pigmented flagellates.

The fourth type of odor is the one which includes those described as "musty" and "earthy." The latter is commonly associated with actinomycetes (3, 4) and with a few algae. It can vary from mild to decidedly pungent. The earthy odor of soil also has been considered to be due to the presence of actinomycetes. The very common musty odor in water is encountered in the presence of certain blue-green algae and a few other forms. It has been described by additional terms such as potato bin and moldy. Some waters have been reported as having weedy, swampy, marshy, peaty, strawlike and woody odors and these are possibly a modification or a combination of the grassy and musty odors.

A "septic" odor has been associated frequently with the presence of large accumulations of blue-green algae and occasionally of the green algae, *Hydrodictyon* and *Cladophora*. Other names applied to this type of odor are pigpen, foul, objectionable, vile, fermentation, and putrefactive (5). As these terms suggest, it is produced as a result of the decomposition of masses of algae, especially where a lack of sufficient oxygen permits the formation of odoriferous intermediate products from the algal proteins.

Chlorophenolic, iodoform, or medicinal odors may be produced by the action of chlorine on the products of certain algae although somewhat similar odors may be present in the water at other times because of industrial wastes.

MEASUREMENT OF ODORS

For the measurement of odors in water the threshold odor test is commonly employed (6). The threshold odors due to algae tend, in some areas, to be comparatively low, ranging from 1 to 14, but in other areas they frequently go up to 30 or 40, and occasionally reach as high as 90 or more. Algal odors are generally objectionable, however, even when the threshold odor number is low. For satisfactory treatment, the threshold odor usually has to be reduced to 5 or less. However, each water supply and often each odor outbreak must be judged independently, in determining the threshold number below which the water is considered palatable.

In some plants the treatment is instituted as soon as any taste and odor algae increase to a predetermined number of areal standard units per ml. The number varies according to the particular kind of alga involved; for *Asterionella* it may be 3,000, and for *Synura*, 200 (7).

Tastes produced by algae are seldom separated from and are often confused with odor. Sweet and bitter are the two tastes which have been recorded and it is quite possible that a sour taste may be present whenever the odor is acid or is the putrefactive, septic, or pigpen type. A salty taste apparently has not been recorded as an accompaniment of the fishy, clam-shell, salt marsh, rockweed, Irish moss, or sea weed-like odors.

An additional sensation which the tongue can detect might be listed as the "feel" or "touch." Included here would be the slick or "oily" feel as well as a "metallic," a "dry," and and an "astringent" sensation. Odor, taste, and feel, as recorded for each algal genus are given in table 5. The word "flavor" could be used as an inclusive term embracing taste, odor, and touch or feel (8).

PRINCIPAL ODOR-PRODUCING ALGAE

Synura is one of the more potent algae in production of an odor in water which is often described as resembling that of a ripe cucumber or muskmelon. A comparatively few colonies per ml. may be sufficient to cause a very perceptible odor. This organism also produces a bitter taste in the water and leaves a persistent dry metallic sensation on the tongue. When present in large numbers, this, as well as other flagellates, may develop a fishy odor. In Massachusetts, for example, *Dinobryon*, *Uroglenopsis*, and the "armored" flagellate *Peridinium* produced a strong fishy odor in a large reservoir holding over 600 million gallons of water. These forms developed in February under a 16-inch layer of ice (9). There is some evidence that *Uroglenopsis* is stimulated to rapid growth following an abundant growth of other algae.

In California one of the worst offenders is the armored flagellate *Ceratium* which produces a fishy to pronounced septic odor. The organism is capable of very rapid multiplication and may develop in large numbers during any season (10).

Table 4.—Taste and Odor Algae, Representative Species

Group and Algae	*Plate*
Blue-Green Algae (Myxophyceae):	
Anabaena circinalis	
Anabaena planctonica	1
Anacystis cyanea	1
Aphanizomenon flos-aquae	1
Cylindrospermum musicola	
Gomphosphaeria lacustris, kuetzingianum type	1
Oscillatoria curviceps	
Rivularia haematites	
Green Algae (nonmotile Chlorophyceae, etc.):	
Chara vulgaris	
Cladophora insignis	
Cosmarium portianum	
Dictyosphaerium ehrenbergianum	
Gloeocystis planctonica	
Hydrodictyon reticulatum	1
Nitella gracilis	1
Pediastrum tetras	
Scenedesmus abundans	
Spirogyra majuscula	
Staurastrum paradoxum	1
Diatoms (Bacillariophyceae):	
Asterionella gracillima	1
Cyclotella compta	
Diatoma vulgare	2
Fragilaria construens	
Stephanodiscus niagarae	
Synedra ulna	1
Tabellaria fenestrata	1
Flagellates (Chrysophyceae, Euglenophyceae, etc.):	
Ceratium hirundinella	1
Chlamydomonas globosa	
Chrysosphaerella longispina	
Cryptomonas erosa	
Dinobryon divergens	1
Euglena sanguinea	
Glenodinium palustre	
Mallomonas caudata	1
Pandorina morum	1
Peridinium cinctum	1
Synura uvella	1
Uroglenopsis americana	1
Volvox aureus	1

Dinobryon develops in the southern end of Lake Michigan, in June and July, almost every year, in numbers sufficient to impart a prominent fishy odor to the water. As many as 700 areal standard units per ml. of this alga have been reported and it has represented, at times, up to 47 percent of the total algal count. Its odor has the reputation of being readily adsorbed by activated carbon. In spite of this, it is estimated that one treatment plant required over $70,000 worth of the carbon to control, for a period of 2 months, the odor due specifically to this alga (11).

Asterionella is considered one of the worst offenders among the diatoms, having a characteristic aromatic geranium-like odor that changes to fishy when the alga is present in large numbers. *Tabellaria* produces a similar effect, while *Synedra* has an earthy to musty odor and *Stephanodiscus* is blamed for a "vegetable to oily taste" with very little odor.

Certain blue-green algae are well known for developing very foul "pigpen" odors in water. Three of these algae, illustrated on plate 1, are *Anabaena*, *Anacystis* (formerly known as *Microcystis*, *Polycystis*, and *Clathrocystis*), and *Aphanizomenon*. All of these are capable of collecting in large masses sufficient to form water "blooms." The foul odor undoubtedly develops from products of decomposition as the algae begin to die off in large numbers. These same blue-green algae, together with others such as *Gomphosphaeria* (which now includes *Coelosphaerium*), *Cylindrospermum*, and *Rivularia* have a natural odor which is commonly described as "grassy." This often changes to the odor of nasturtium stems, probably as a result of oxidation.

Green algae are less often associated with tastes and odors in water. In fact, their growth may help to keep in check the blue-green algae and the diatoms and thus be a positive factor in the control of water quality. However, *Hydrodictyon* (water net), the desmid, *Staurastrum*, and the large massive stone-warts, *Nitella* and *Chara*, may offend rather than help in this biological competition between types. *Dictyosphaerium* is regarded as one of the worst offenders among the green algae, giving a fishy, as well as a grassy to nasturtium odor (12). Some of the swimming green algae which are listed with the flagellates, including *Volvox*, *Pandorina*, and *Chlamydomonas*, are able to produce fishy odors.

Research is now being conducted at the Robert A. Taft Sanitary Engineering Center to determine what particular

Table 5.—Odors, Tastes, and Tongue Sensations Associated With Algae in Water

Algal genus	Algal group	Odor when algae are—		Taste	Tongue sensation
		Moderate	Abundant		
Actinastrum	Green		Grassy, musty		
Anabaena	Blue-green	Grassy, nasturtium, musty.	Septic		
Anabaenopsis	Blue-green		Grassy		
Anacystis	Blue-green	Grassy	Septic	Sweet	
Aphanizomenon	Blue-green	Grassy, nasturtium, musty.	Septic	Sweet	Dry.
Asterionella	Diatom	Geranium, spicy	Fishy		
Ceratium	Flagellate	Fishy	Septic	Bitter	
Chara	Green	Skunk, garlic	Spoiled, garlic		
Chlamydomonas	Flagellate	Musty, grassy	Fishy, septic	Sweet	Slick.
Chlorella	Green		Musty		
Chrysosphaerella	Flagellate		Fishy		
Cladophora	Green		Septic		
(Clathrocystis)	See Anacystis.				
Closterium	Green		Grassy		
(Coelosphaerium)	See Gomphosphaeria.				
Cosmarium	Green		Grassy		
Cryptomonas	Flagellate	Violet	Violet	Sweet	
Cyclotella	Diatom	Geranium	Fishy		
Cylindrospermum	Blue-green	Grassy	Septic		
Diatoma	Diatom		Aromatic		
Dictyosphaerium	Green	Grassy, nasturtium	Fishy		
Dinobryon	Flagellate	Violet	Fishy		Slick.
Eudorina	Flagellate		Fishy		
Euglena	Flagellate		Fishy	Sweet	
Fragilaria	Diatom	Geranium	Musty		
Glenodinium	Flagellate		Fishy		Slick.
(Gloeocapsa)	See Anacystis.				
Gloeocystis	Green		Septic		
Gloeotrichia	Blue-green		Grassy		
Gomphosphaeria	Blue-green	Grassy	Grassy	Sweet	
Gonium	Flagellate		Fishy		
Hydrodictyon	Green		Septic		
Mallomonas	Flagellate	Violet	Fishy		
Melosira	Diatom	Geranium	Musty		Slick.
Meridion	Diatom		Spicy		
(Microcystis)	See Anacystis.				
Nitella	Green	Grassy	Grassy, septic	Bitter	
Nostoc	Blue-green	Musty	Septic		
Oscillatoria	Blue-green	Grassy	Musty, spicy		
Pandorina	Flagellate		Fishy		
Pediastrum	Green		Grassy		
Peridinium	Flagellate	Cucumber	Fishy		
Pleurosigma	Diatom		Fishy		
Rivularia	Blue-green	Grassy	Musty		
Scenedesmus	Green		Grassy		
Spirogyra	Green		Grassy		
Staurastrum	Green		Grassy		
Stephanodiscus	Diatom	Geranium	Fishy		Slick.
Synedra	Diatom	Grassy	Musty		Slick.
Synura	Flagellate	Cucumber, muskmelon, spicy.	Fishy	Bitter	Dry, metallic, slick.
Tabellaria	Diatom	Geranium	Fishy		
Tribonema	Green		Fishy		
(Uroglena)	See Uroglenopsis.				
Uroglenopsis	Flagellate	Cucumber	Fishy		Slick.
Ulothrix	Green		Grassy		
Volvox	Flagellate	Fishy	Fishy		

species of algae produce tastes and odors in water and under what conditions this takes place. Suspected forms are obtained in pure growth cultures for this work (13) and chemical analyses are being made of their products and of various organic wastes which have odor (14). Additional research is being directed toward the finding of algicides which are sufficiently selective to destroy certain taste and odor algae without at the same time being wasted on nonoffending types (15). The relationship of actinomycetes to earthy odors in water is also being studied.

The following statement by Laughlin (16) is an expression of the emphasis which the control of taste and odor problems must be given in modern programs for water treatment: "It is one of the basic duties and responsibilities of the water purification plant operator to furnish his public with a palatable water 24 hours a day. * * * The presence of any objectionable odor may cause the consumer to go to a more palatable but unsafe water supply. Therefore, the importance of producing a palatable water cannot be overemphasized."

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CHAPTER V

FILTER CLOGGING ALGAE

AS WATER passes through a sand filter in the treatment plant the spaces between the grains of sand become filled with colloidal and solid particles which had been dispersed in the water. If the raw water comes from a surface supply such as a reservoir, lake, or stream, the algae which are invariably present will be well represented in the material collected by the sand filter. They are frequently the primary causes for the clogging of the filter.

In most places the algae and other particulate materials are sufficiently numerous throughout most of the year to require that the water be treated by coagulation and sedimentation previous to filtration through sand. Without this preliminary treatment the filter would clog so rapidly that it would be uneconomical to use, except when relatively clear water is available. Certain plants in California and in Canada have been using the rapid sand filter without prior coagulation at least during portions of the year (1).

Efficient coagulation and sedimentation may remove up to 90 or 95 percent of the algae from the water. The algae remaining in the water may still be sufficient to cause gradual or even rapid loss of head in the sand filter. The clogged filter must then be taken out of service and cleaned or backwashed. Normal filter runs commonly extend for from 30 to 100 hours before cleaning is required, while short filter runs, caused by the presence of algae, are even less than 10 hours in length (2). In extreme cases the clogging may recur so frequently that the amount of water required to backwash the filter is greater than the amount of filtered water which reaches the distribution system. Thus the presence of algae can slow up the process of water treatment and add materially to its cost.

CLOGGING PROCESSES

Both the slow and rapid sand filters may become clogged with algae, but in the former the algae and other aquatic microorganisms may play a useful part in the treatment process. They form a loose, slimy layer over the surface of the sand and act as a filter. The algae in this layer release oxygen during photosynthesis, and the oxygen in turn is utilized by aerobic saprophytic bacteria, fungi, and protozoa which establish themselves in and on the filter. This permits the decomposition or stabilization of the organic material that was present in the raw water. Diatoms, however, due to their rigid walls, may do more harm than good by speeding the clogging of the filter, but it has been possible to use slow sand filters when diatoms have put rapid filters out of commission (3). The water that has passed through a slow sand filter is relatively free of bacteria, algae, and other organisms as well as of dead organic matter.

It is not yet fully understood why certain algae are more effective than others in reducing the movement of water through the filters. Ability to develop in large numbers is certainly one essential. The rigid wall, such as is found in the diatoms, the copious mucilaginous material around the cells as in the case of *Palmella*, and the tendency to form flakes or a network of strands, as in *Fragilaria* and *Tribonema* are other factors.

Diatoms are present during all seasons of the year and are by far the most important group of organisms which clog filters. The most serious offenders are *Asterionella*, *Fragilaria*, *Tabellaria*, and *Synedra*. Other diatoms that may occasionally cause this trouble include *Navicula*, *Cyclotella*, *Diatoma*, and *Cymbella*, all of which are illustrated on plate 2. The rigid cell wall of diatoms is composed principally of silica and is not subject to decomposition. Therefore, even though the diatoms may die off rapidly on the surface of the filter, their silica walls remain to plug the pores in the sand.

In England a relatively pure growth of *Fragilaria* developed in a reservoir to the extent that it was necessary to remove huge quantities of this diatom at the water treatment plant. Counts of another filter clogging diatom, *Asterionella*, indicated that the organism has reached a density as high as 20,000 per ml. (4).

In Chicago, when the water to be filtered contained approximately 700 microorganisms per ml., principally *Tabellaria* and *Fragilaria*, the filter runs were only 4.5 hours. Three days later, when the count was down to approximately 100 per ml., the filter run increased to 41 hours (5). In Washington, D.C., filter runs were reduced from an average of 50 hours to less than 1 hour due to the sudden influx of the diatom *Synedra*, which had a concentration in the raw water reaching 4,800 cells per ml. (6).

The filter clogging blue-green algae are represented on plate 2 by *Anacystis* (*Chroococcus* type), *Rivularia*, *Anabaena*, and three species of *Oscillatoria*. *Anabaena* is known to have caused filter trouble in Illinois and Minnesota while *Oscillatoria* is one of the offenders in Switzerland. *Dinobryon* and *Trachelomonas* are pigmented flagellates, the former being common in the Great Lakes and in the soft waters of the eastern United States. *Chlorella*, *Palmella*, *Spirogyra*, and the desmid, *Closterium*, are green algae while *Tribonema* is a yellow-green filament. *Chlorella* is the alga which has given trouble by clogging filters made of glass wool. In addition, it grows on the inner surfaces of the glass bottle in water coolers and in water lines constructed of plastic tubing, when these have been exposed to light. In the tropics and warm temperate zone, the filamentous green algae are often the common offenders in clogging of sand filters.

Forty-three of the more important filter clogging algae are listed alphabetically under their major groups in table 6, below. Twenty-two of these are illustrated in color on plate 2, while a few of the remaining forms are to be found on the other plates as indicated in the table.

Table 6.—Filter Clogging Algae

Group and Algae	*Plate*
Blue-Green Algae (Myxophyceae):	
Anabaena flos-aquae	2
Anacystis dimidiata (Chroococcus turgidus)	2
Gloeotrichia echinulata	
Oscillatoria amphibia	
Oscillatoria chalybea	2
Oscillatoria ornata	
Oscillatoria princeps	2
Oscillatoria pseudogeminata	
Oscillatoria rubescens	
Oscillatoria splendida	2
Rivularia dura	2
Green and Yellow-Green Algae (nonmotile Chlorophyceae, etc.)·	
Chlorella pyrenoidosa	2
Cladophora aegagropila	
Closterium moniliferum	2
Dichotomosiphon tuberosus	
Dictyosphaerium pulchellum	
Hydrodictyon reticulatum	1
Mougeotia sphaerocarpa	
Palmella mucosa	2
Spirogyra porticalis	2
Tribonema bombycinum	2
Ulothrix variabilis	
Zygnema insigne	
Diatoms (Bacillariophyceae):	
Asterionella formosa	2
Cyclotella meneghiniana	2
Cymbella ventricosa	2
Diatoma vulgare	2
Fragilaria crotonensis	2
Melosira granulata	2
Melosira varians	
Navicula graciloides	2
Navicula lanceolata	
Nitzschia palea	3
Stephanodiscus binderanus	
Stephanodiscus hantzschii	5
Synedra acus	2
Synedra acus var. radians (S. delicatissima)	
Synedra pulchella	
Tabellaria fenestrata	1
Tabellaria flocculosa	2
Pigmented Flagellates (Chrysophyceae, etc.):	
Dinobryon sertularia	2
Peridinium wisconsinense	
Trachelomonas crebea	2

Most of the microscopic organisms present in water that is passing through a rapid sand filter generally will be caught in the top one-half inch of the sand. This is particularly the case when the organisms are abundant in the water. A few of the organisms will penetrate deeper into the filter bed while others disintegrate quickly as they come in contact with the sand. The longer the filter run the greater the percentage of organisms that will penetrate below the top one-half inch.

In Chicago, a study was made of the numbers of certain diatoms that were caught on the surface of rapid sand filters. The samples were collected immediately before the filters were backwashed. During 1 year of this study, *Tabellaria* ranged in numbers from 496,000 to 936,000 per square inch of filter surface in April, and from 1,824,000 to 8,016,000 in November. In contrast, the range for *Melosira* was from 784,000 to 2,624,000 in April, and only 16,000 to 416,000 in November (7).

The relationships of algae to sand filters involve also the problem caused by passage of certain algae through both rapid and slow filters and into the treated water. A number of the same algae that can clog filters have at other times been offenders in penetrating them. Algae that have passed through rapid filters include *Synedra* and *Oscillatoria* and through slow filters, *Chlamydomonas*, *Euglena*, *Navicula*, *Nitzschia*, *Phacus*, and *Trachelomonas* (8). The ease with which the algae penetrate depends upon several factors, the principal ones being the rate of flow, the grade of sand used, and the type of organism. Very minute algae and flagellates penetrate with greater facility than other types. When the penetration is slow, it may be a few hours before the algae reach the underdrains. Frequent backwashing, even when the filter is not clogged will tend to remove the algae and reduce the number that would reach the filtered water.

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Color Plates 1 to 6

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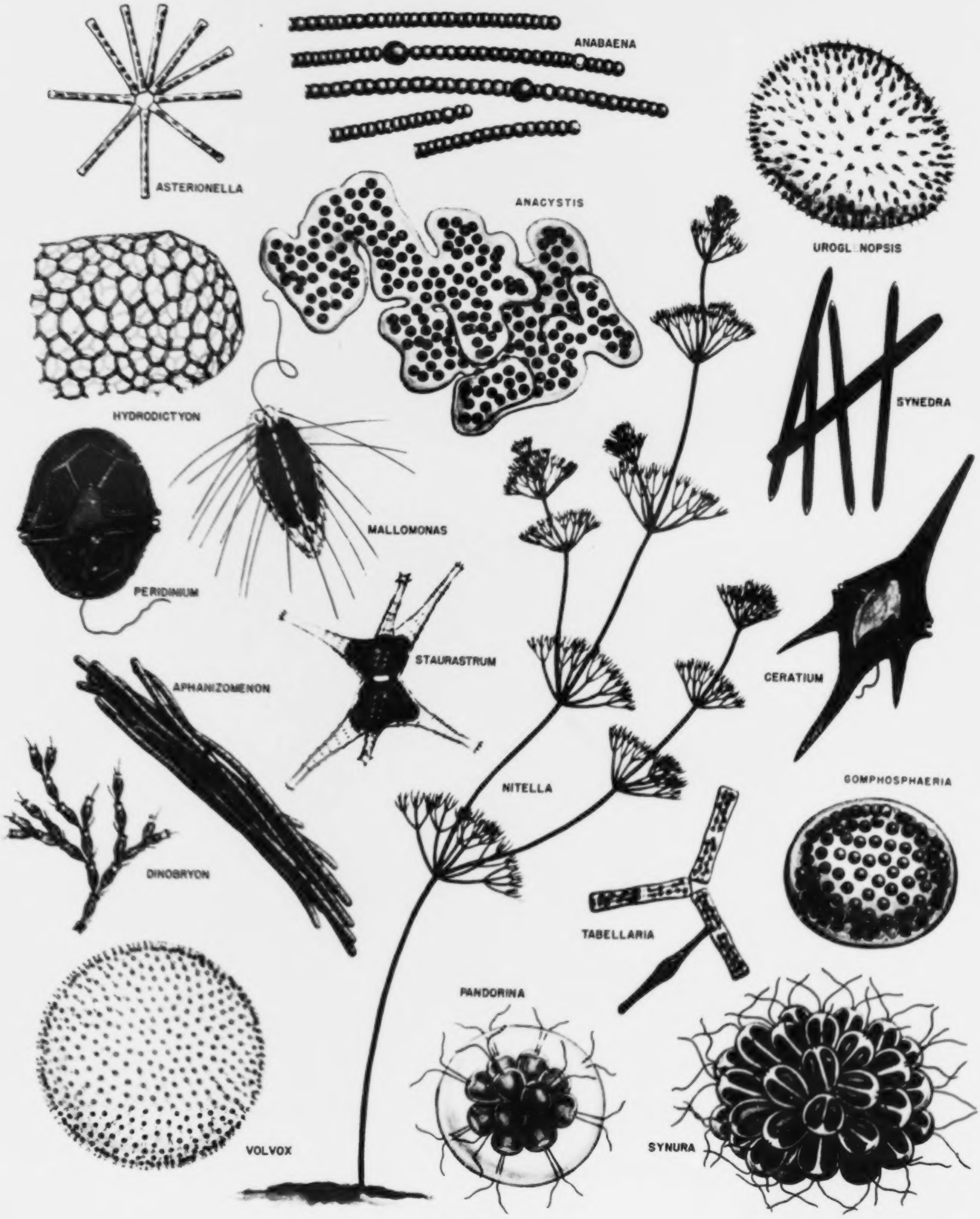
ALGAE IMPORTANT IN WATER SUPPLIES

TASTE AND ODOR ALGAE


ANABAENA
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ANACYSTIS
UROGLENOPSIS
HYDRODICTYON
SYNEDRA
MALLOMONAS
PERIDINIUM
STAURASTRUM
APHANIZOMENON
CERATIUM
NITELLA
GOMPHOSPHAERIA
DINOBRYON
TABELLARIA
PANDORINA
VOLVOX
SYNURA

PLATE I

PLATE 1

TASTE AND ODOR ALGAE

Species Names	*Linear Magnifications*
Anabaena planctonica	250
Anacystis cyanea	250
Aphanizomenon flos-aquae	250
Asterionella gracillima	250
Ceratium hirundinella	250
Dinobryon divergens	250
Gomphosphaeria lacustris, kuetzingianum type	500
Hydrodictyon reticulatum	10
Mallomonas caudata	500
Nitella gracilis	1
Pandorina morum	500
Peridinium cinctum	500
Staurastrum paradoxum	500
Synedra ulna	250
Synura uvella	500
Tabellaria fenestrata	250
Uroglenopsis americana	125
Volvox aureus	125

FILTER CLOGGING ALGAE

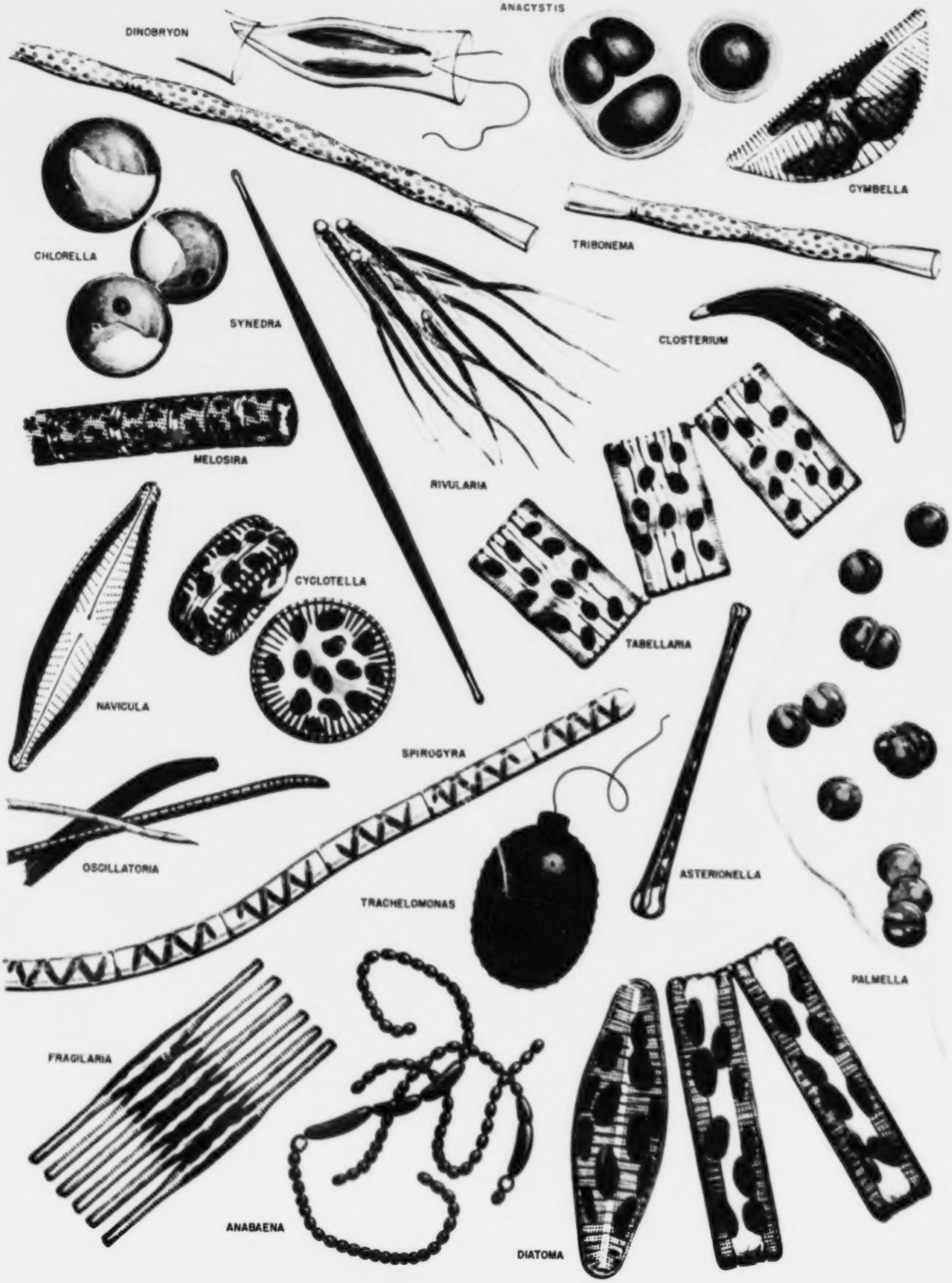

DINOBRYON
ANACYSTIS
CYMBELLA
TRIBONEMA
CHLORELLA
SYNEDRA
CLOSTERIUM
MELOSIRA
RIVULARIA
CYCLOTELLA
TABELLARIA
NAVICULA
SPIROGYRA
OSCILLATORIA
ASTERIONELLA
TRACHELOMONAS
PALMELLA
FRAGILARIA
ANABAENA
DIATOMA

PLATE 2

PLATE 1

TASTE AND ODOR ALGAE

Species Names	*Linear Magnifications*
Anabaena planctonica	250
Anacystis cyanea	250
Aphanizomenon flos-aquae	250
Asterionella gracillima	250
Ceratium hirundinella	250
Dinobryon divergens	250
Gomphosphaeria lacustris, kuetzingianum type	500
Hydrodictyon reticulatum	10
Mallomonas caudata	500
Nitella gracilis	1
Pandorina morum	500
Peridinium cinctum	500
Staurastrum paradoxum	500
Synedra ulna	250
Synura uvella	500
Tabellaria fenestrata	250
Uroglenopsis americana	125
Volvox aureus	125

PLATE 2

FILTER CLOGGING ALGAE

Species Names	*Linear Magnifications*
Anabaena flos-aquae	500
Anacystis dimidiata	1000
Asterionella formosa	1000
Chlorella pyrenoidosa	5000
Closterium moniliferum	250
Cyclotella meneghiniana	1500
Cymbella ventricosa	1500
Diatoma vulgare	1500
Dinobryon sertularia	1500
Fragilaria crotonensis	1000
Melosira granulata	1000
Navicula graciloides	1500
Oscillatoria princeps (top)	250
Oscillatoria chalybea (middle)	250
Oscillatoria splendida (bottom)	500
Palmella mucosa	1000
Rivularia dura	250
Spirogyra porticalis	125
Synedra acus	500
Tabellaria flocculosa	1500
Trachelomonas crebea	1500
Tribonema bombycinum	500

POLLUTED WATER ALGAE

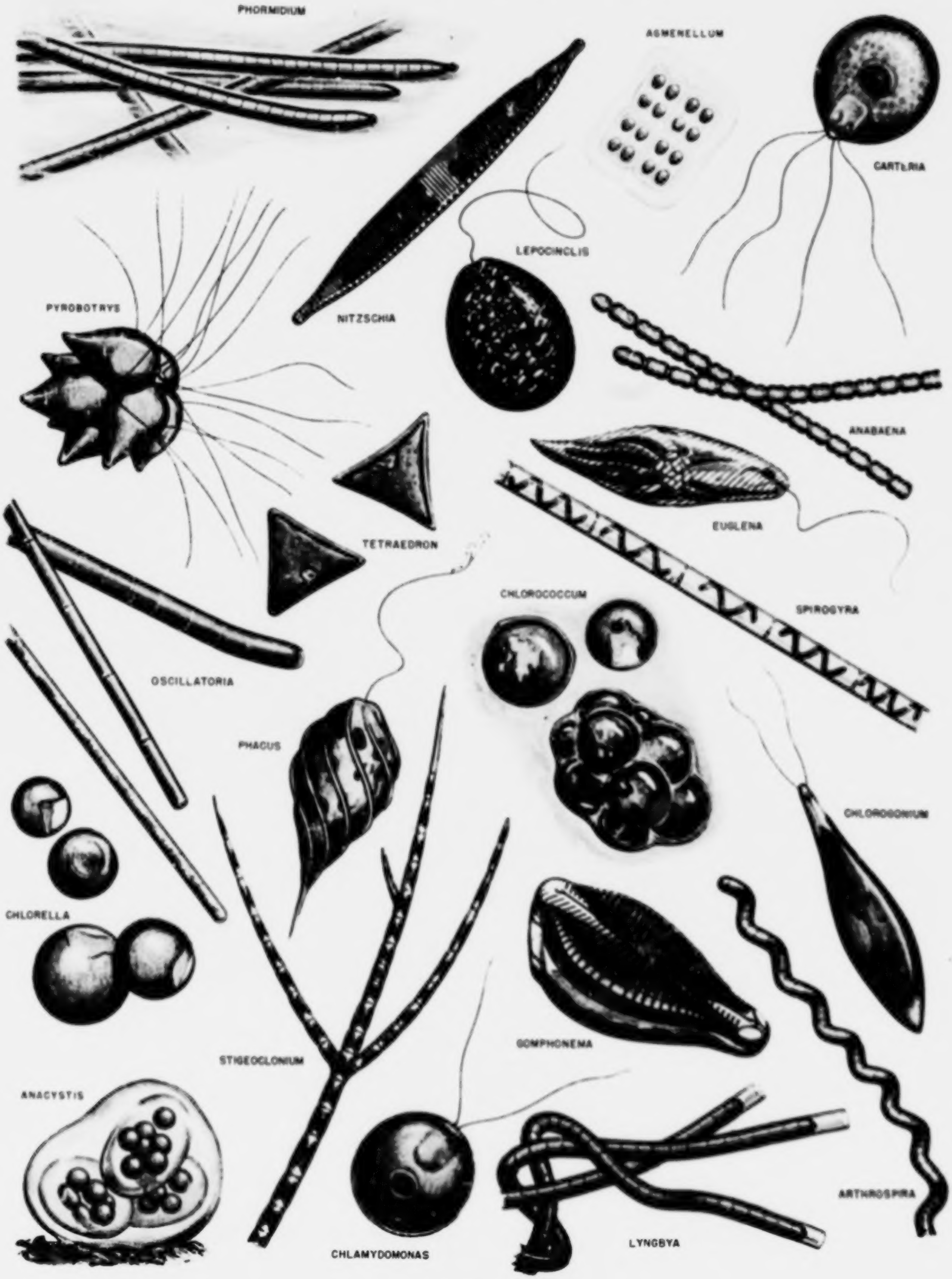

PHORMIDIUM
AGMENELLUM
CARTERIA
LEPOCINCLIS
PYROBOTRYS
NITZSCHIA
ANABAENA
EUGLENA
TETRAEDRON
CHLOROCOCCUM
SPIROGYRA
OSCILLATORIA
PHACUS
CHLOROGONIUM
CHLORELLA
GOMPHONEMA
STIGEOCLONIUM
ANACYSTIS
ARTHROSPIRA
LYNGBYA
CHLAMYDOMONAS

PLATE 3

PLATE 3

POLLUTED WATER ALGAE

Species Names	*Linear Magnifications*
Agmenellum quadriduplicatum, tenuissima type	1000
Anabaena constricta	500
Anacystis montana	1000
Arthrospira jenneri	1000
Carteria multifilis	2000
Chlamydomonas reinhardi	1500
Chlorella vulgaris	2000
Chlorococcum humicola	1000
Chlorogonium euchlorum	1500
Euglena viridis	1000
Gomphonema parvulum	3000
Lepocinclis texta	500
Lyngbya digueti	1000
Nitzschia palea	2000
Oscillatoria chlorina (top)	1000
Oscillatoria putrida (middle)	1000
Oscillatoria lauterbornii (bottom)	1000
Phacus pyrum	1500
Phormidium autumnale	500
Pyrobotrys stellata	1500
Spirogyra communis	250
Stigeoclonium tenue	500
Tetraedron muticum	1500

PLATE 4

CLEAN WATER ALGAE

Species Names	*Linear Magnifications*
Agmenellum quadriduplicatum, glauca type	250
Ankistrodesmus falcatus var. acicularis	1000
Calothrix parietina	500
Chromulina rosanoffi	4000
Chrysococcus rufescens	4000
Cladophora glomerata	100
Coccochloris stagnina	1000
Cocconeis placentula	1000
Cyclotella bodanica	500
Entophysalis lemaniae	1500
Hildenbrandia rivularis	500
Lemanea annulata	1
Meridion circulare	1000
Micrasterias truncata	250
Microcoleus subtorulosus	500
Navicula gracilis	1000
Phacotus lenticularis	2000
Pinnularia nobilis	250
Rhizoclonium hieroglyphicum	250
Rhodomonas lacustris	3000
Staurastrum punctulatum	1000
Surirella splendida	500
Ulothrix aequalis	250

PLANKTON AND OTHER SURFACE WATER ALGAE

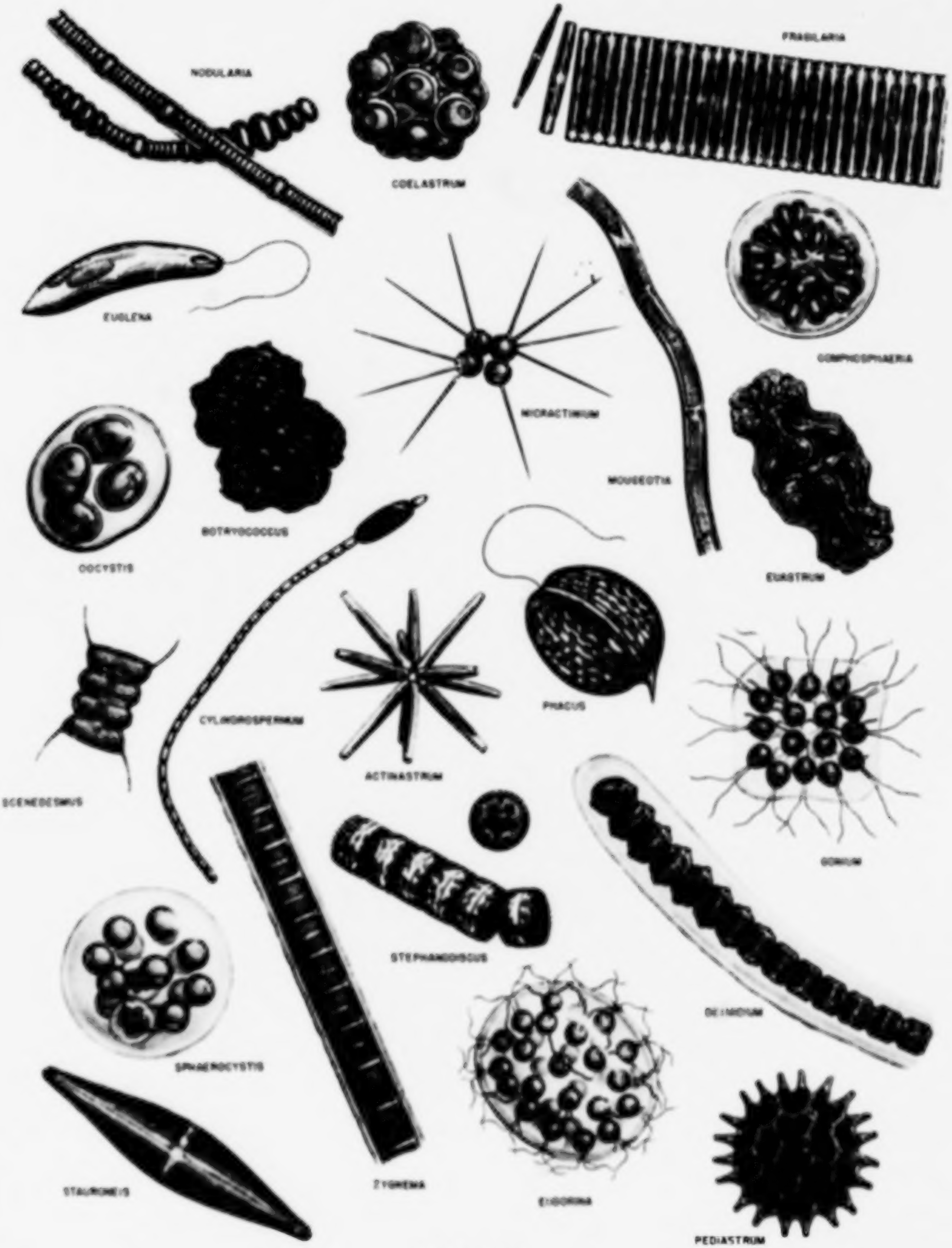

NODULARIA
COELASTRUM
FRAGILARIA
EUGLENA
MICRACTINIUM
GOMPHOSPHAERIA
MOUGEOTIA
BOTRYOCOCCUS
OOCYSTIS
EUASTRUM
CYLINDROSPERMUM
ACTINASTRUM
PHACUS
SCENEDESMUS
GONIUM
STEPHANODISCUS
DESMIDIUM
SPHAEROCYSTIS
STAURONEIS
ZYGNEMA
EUDORINA
PEDIASTRUM

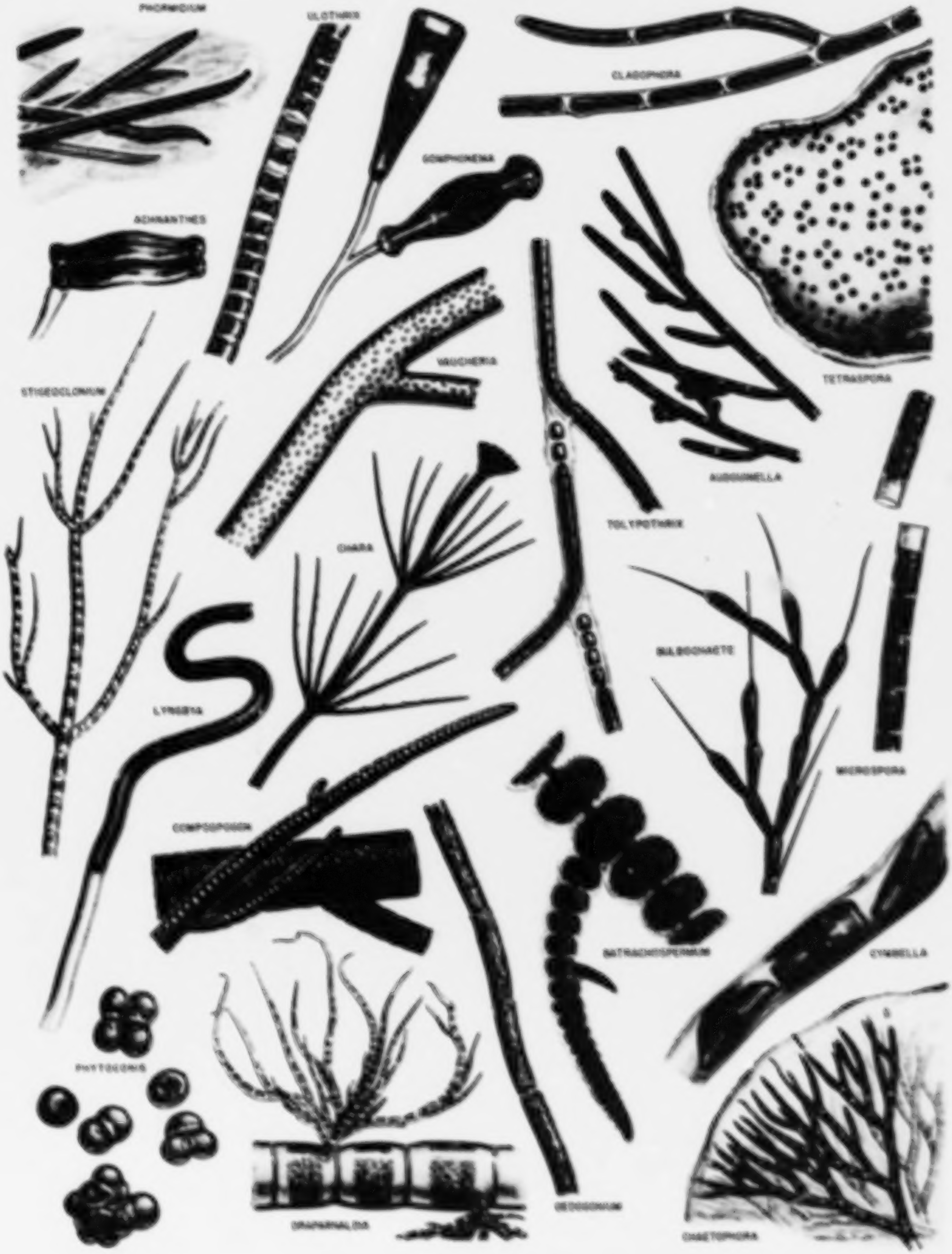
PLATE 5

PLATE 5

PLANKTON AND OTHER SURFACE WATER ALGAE

Species Names	*Linear Magnifications*
Actinastrum gracillimum	1000
Botryococcus braunii	1000
Coelastrum microporum	500
Cylindrospermum stagnale	250
Desmidium grevillei	250
Euastrum oblongum	500
Eudorina elegans	250
Euglena gracilis	1000
Fragilaria capucina	1000
Gomphosphaeria aponina	1500
Gonium pectorale	500
Micractinium pusillum	1000
Mougeotia scalaris	250
Nodularia spumigena	500
Oocystis borgei	1000
Pediastrum boryanum	125
Phacus pleuronectes	500
Scenedesmus quadricauda	1000
Sphaerocystis schroeteri	500
Stauroneis phoenicenteron	500
Stephanodiscus hantaschii	1000
Zygnema sterile	250

ALGAE GROWING ON RESERVOIR WALLS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ULOTHRIX
CLADOPHORA
GOMPHONEMA
ACHNANTHES
TETRASPORA
VAUCHERIA
STIGEOCLONIUM
AUDOUINELLA
TOLYPOTHRIX
CHARA
BULBOCHAETE
LYNGBYA
MICROSPORA
COMPSOPOGON
BATRACHOSPERMUM
CYMBELLA
PHYTOCONIS
OEDOGONIUM
DRAPARNALDIA
CHAETOPHORA

PLATE 6

PLATE 6

ALGAE GROWING ON RESERVOIR WALLS

Species names	*Linear magnifications*
Achnanthes microcephala	1500
Audouinella violacea	250
Batrachospermum moniliforme	3
Bulbochaete insignis	125
Chaetophora elegans	250
Chara globularis	4
Cladophora crispata	125
Compsopogon coeruleus	125
Cymbella prostrata	250
Draparnaldia glomerata	125
Gomphonema geminatum	250
Lyngbya lagerheimii	1000
Microspora amoena	250
Oedogonium suecicum	500
Phormidium uncinatum	250
Phytoconis botryoides	1000
Stigeoclonium lubricum	250
Tetraspora gelatinosa	125
Tolypothrix tenuis	500
Ulothrix zonata	250
Vaucheria sessilis	125

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CHAPTER VI

POLLUTED WATER ALGAE

WATER CONTAINING one or more of various types of "impurities" may be said to be "polluted." The term *pollution* is usually restricted to situations in which the condition is considered potentially harmful to human health or capable of interfering seriously with the use of the water or its immediate environment. Most of the information at present available on algae in relation to polluted water is limited to water containing treated or untreated domestic sewage and closely related organic wastes. The following account, therefore, will deal primarily with this type of water pollution.

After domestic sewage or effluent has polluted a body of water such as a stream, the algae present react in a manner that has come to be recognized as of considerable importance. During the process of natural purification, the algae oxygenate the water, and also utilize byproducts of the purification process. The kinds and numbers of algae and other organisms in the polluted portion of a stream are different from those present in the unpolluted portion above the sewer outlet. As the sewage goes through stages of decomposition in the stream, the numbers and kinds of microorganisms continue to change until eventually the aquatic flora and fauna in the purified water become somewhat similar to those found above the point of pollution. The algae represent a conspicuous and significant group in this continuously changing population in a stream. The variation in the algal population at different points or under different conditions of pollution constitutes one of the indices that can be applied to any desired location in the stream to determine the presence or absence of domestic sewage or other putrescible wastes, or to measure the degree of recovery from pollution with these wastes.

It appears evident to many workers that particular genera or even species of algae, when considered alone, are not reliable indicators of organic pollution. However, when a number of kinds of algae are considered as a community, that group may be a reliable index. Lists of algae and other organisms indicative of the various pollution zones in a stream have been compiled, including those by Kolkwitz (1), Liebmann (2), and Whipple, Fair, and Whipple (3).

Emphasis in this account is placed on the algae which various workers have found to be present and relatively prominent or persistent in the polysaprobic and alpha-mesosaprobic zones of polluted streams. These names for the zones, however, have been used by comparatively few workers who have reported on sewage-tolerant algae, and their findings have had to be interpreted in such a way as to combine the information from the many sources.

Reports of more than 50 workers have been examined for names of algae commonly found in waters containing a high concentration of organic wastes. From these, a total of more than 500 species of algae has been compiled by the writer (4). Forty-seven of the more important species from this group have been selected and are given in table 7, and 23 of these pollution algae are illustrated in color on plate 3.

Table 7.—Pollution Algae—Algae Common in Organically Enriched Areas

Group and Algae	*Plate or Figure*
Blue-Green Algae (Myxophyceae):	
Agmenellum quadriduplicatum, tenuissima type	3
Anabaena constricta	3
Anacystis montana	3
Arthrospira jenneri	3
Lyngbya digueti	3
Oscillatoria chalybea	3
Oscillatoria chlorina	3
Oscillatoria formosa	
Oscillatoria lauterbornii	3
Oscillatoria limosa	Fig. 29
Oscillatoria princeps	2
Oscillatoria putrida	3
Oscillatoria tenuis	Fig. 30
Phormidium autumnale	3
Phormidium uncinatum	6
Green Algae (nonmotile Chlorophyceae):	
Chlorella pyrenoidosa	2
Chlorella vulgaris	3
Chlorococcum humicola	3
Scenedesmus quadricauda	5
Spirogyra communis	3
Stichococcus bacillaris	
Stigeoclonium tenue	3
Tetraedron muticum	3
Diatoms (Bacillariophyceae):	
Gomphonema parvulum	3
Hantzschia amphioxys	
Melosira varians	
Navicula cryptocephala	
Nitzschia acicularis	
Nitzschia palea	3
Surirella ovata	
Flagellates (Euglenophyceae, Volvocales of Chlorophyceae):	
Carteria multifilis	3
Chlamydomonas reinhardi	3
Chlorogonium euchlorum	3
Cryptoglena pigra	
Euglena agilis	
Euglena deses	
Euglena gracilis	5
Euglena oxyuris	
Euglena polymorpha	
Euglena viridis	3
Lepocinclis ovum	
Lepocinclis texta	3
Pandorina morum	1
Phacus pyrum	3
Pyrobotrys gracilis	
Pyrobotrys stellata	3
Spondylomorum quaternarium	

Many genera of algae include certain species that are tolerant of organic enrichment and others that are not. This is particularly true of *Chlamydomonas*, *Euglena*, *Navicula*, *Oscillatoria*, *Phormidium*, and *Synedra*. In a few instances the same thing may be true also for strains or varieties of a species. For example, Fjerdingstad (5) claims that there are two separate strains of the species *Ulothrix zonata*, (fig. 29) the pollution type and the pure water type.

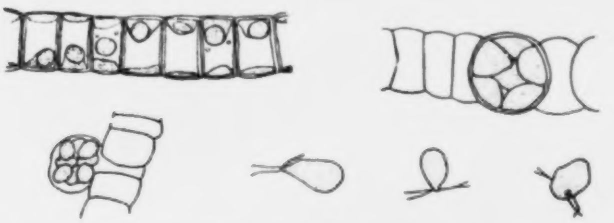

Figure 29.—Ulothrix zonata, vegetative filament and stages in spore production. Its two strains react differently to pollution.

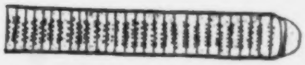

Figure 30.—*Oscillatoria limosa.*

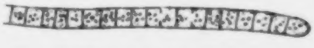

Figure 31.—*Oscillatoria tenuis.*

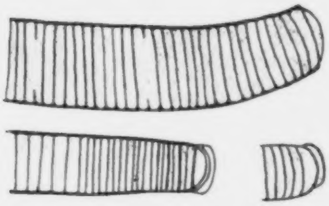

Figure 32.—*Oscillatoria princeps.*

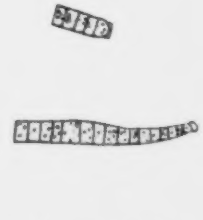

Figure 33.—*Phormidium uncinatum.*

Included in the group of pollution algae are some forms of unusual interest. *Euglena viridis*, *Nitzschia palea*, *Oscillatoria limosa* (fig. 30) and *Oscillatoria tenuis* (fig. 31) have been listed by workers more often than any other species as reliable indicators of organic pollution (5). Next in order are *Arthrospira jenneri*, *Stigeoclonium tenue*, *Euglena gracilis*, and *Chlorella vulgaris*. *Anabaena constricta*, *Chlorella vulgaris*, and *Euglena viridis* are encountered also on sludge or in retention basins of sewage treatment plants. *Chlorella* is the alga that grows readily in artificial culture media and is being used in a number of laboratories to determine the feasibility of producing algae on a large scale for food, animal feed, and other products. Two additional blue-green algae tolerant of organic enrichment are *Oscillatoria princeps* (fig. 32) and *Phormidium uncinatum* (fig. 33).

The blue-green algae and the flagellates are the algal groups most frequently encountered in the portion of a stream containing organic wastes. Not all representatives of the "blue-green" algae are actually blue-green in color For example, the three species of *Oscillatoria* illustrated on plate 3 tend to be decidedly yellow-green, although they belong to the above group. The flagellate green alga, *Chlamydomonas*, is one of the very common organisms in water. There being a large number of species of this genus and also chlamydomonad stages of other algae, workers generally have not identified the particular species of this genus which they have encountered in polluted water. It is probable that there are a number of species other than the *Chlamydomonas reinhardi* shown on plate 3 which could be listed as algae indicative of organic pollution.

Many of the nonswimming green algae with rounded cells are difficult to identify correctly and often have been mistakenly labeled *Protococcus* (name now changed to *Phytoconis*), a type which is common on moist surfaces of tree trunks and which is attached and not normally planktonic. The two genera of green algae with rounded cells that are included here as pollution algae are *Chlorella* and *Chlorococcum*, both of which are illustrated on plate 3.

ALGAE AND SEWAGE TREATMENT

Treatment and disposal of sewage are an essential process in all large cities and in an increasing number of smaller communities. Extensive treatment plants are equipped with settling basins, gravel beds, large and complicated machinery, and well-equipped laboratories. The actual decomposition of the sewage, however, is almost invariably brought about by microorganisms. Chemical or physical methods such as the use of strong acids or drying and burning are generally too expensive in comparison with the biological treatment.

In this biological process several types of microorganisms are frequently involved. The treatment plant operation consists primarily of making conditions ideal for the rapid development of bacteria, molds, protozoa, and rotifers, since it is through the activities of these microorganisms that the sewage is changed from an offensive to an inoffensive condition (6).

Recently algae have received more attention for the part they are able to play in sewage treatment. In sewage stabilization ponds or lagoons, algae can be utilized for the production of oxygen essential to the growth of the bacteria and other organisms that break down the organic wastes. With algae it is possible to support immense populations of aerobic bacteria, and the sewage stabilization process is greatly accelerated. Large open shallow basins or waste stabilization ponds are required in order that light will be available through the liquid to stimulate algal growth and activity. Certain kinds of algae are able to grow in the presence of a high concentration of sewage and these may be stimulated to grow and multiply very rapidly. It appears that only young algal cells will produce large quantities of oxygen, thus making it desirable that the multiplication of additional young cells be kept up as a continuous process at the sewage treatment plant. The sewage is emptied into the shallow open basin or lagoon and allowed to move slowly through it while the algae multiply rapidly and produce the oxygen. The algae which develop in large numbers in sewage stabilization ponds and lagoons are the same kinds that are present in the portions of streams which are polluted with organic wastes (7).

The massive growths of algae developed in sewage stabilization ponds and lagoons may eventually become a new source of fertilizer, vitamins, animal feed, and other products for commerce. Algae also are potentially valuable as efficient users of the nutrient salts resulting from decomposition of sewage, so that algae might supplement the land plants grown on farms in producing many kinds of organic products useful to man. Thus the pollution algae may become useful not only as indicators and as purifiers but as producers.

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CHAPTER VII

CLEAN WATER ALGAE

CLEAN WATER organisms are those found in water which is free of sewage or other organic enrichment due to waste discharge. The clean water may be that portion of streams above sewage outlets or far enough downstream for the sewage to have been reduced to relatively inoffensive salts and other simple compounds. Most of these products of sewage decomposition are nutrients and will stimulate organisms such as algae to grow much more profusely than they do in the stream above the sewage outlet, where nutrients are limited in quantity. The kinds of algae in the clean waters upstream and downstream tend to be similar, however.

Large numbers of algae will be found in the section of the stream often called the "recovery zone" which contains partially decomposed sewage. It is difficult to select particular algae as the best indicators of the downstream clean water zone, since it is adjacent to the "recovery zone" where purification is still in progress. As with the polluted water forms, it is more satisfactory to emphasize the presence or absence of several of the clean water algae rather than of any one species alone in defining the clean water zone.

Forty-six species have been selected as representative of the clean water algae and are listed in table 8. Twenty-three of these species are illustrated in color on plate 4. The group includes several diatoms, several brown to reddish flagellates, certain greens and blue-greens, and a few fresh-water red algae of the class Rhodophyceae. A number of them, particularly the flagellates, are very minute and appear small even under the high power of a compound microscope, but they frequently are better indicators of clean water than many larger algae that may be mixed with them. However, a few of the larger forms are also useful in indicating the condition of the water and are represented by certain species of *Cladophora*, *Rhizoclonium*, *Lemanea*, and others.

Some of the clean water algae are planktonic, while others are attached to rocks or other material at the bottom or sides of the stream like *Calothrix parietina* (fig. 34). The blue-green alga *Entophysalis lemaniae* (formerly called *Chamaesiphon incrustans*) and the diatom *Cocconeis placentula* are epiphytic, i.e., algae which grow attached to the surface of other plants in the water.

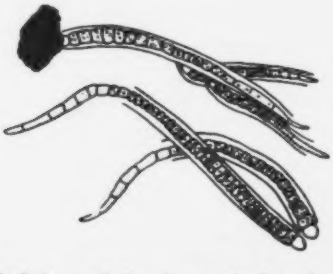

Figure 34.—*Calothrix parietina* is attached to logs and stones in running water.

Several of the genera with clean water species include also other species whose reaction to sewage pollution is different from the clean water forms. Both the pollution and clean water groups are represented by contrasting species of *Navicula*, *Nitzschia*, *Phormidium*, *Agmenellum*, *Surirella*, *Ulothrix*, and *Euglena*. In these same genera, as well as in *Pinnularia*, *Cyclotella*, and *Cladophora*, there are also species considered to be indifferent to sewage. Identification to species is, therefore, essential for any accurate differentiation of pollution zones through the use of algae as indicator organisms.

Clean water algae are commonly listed by some writers as typical of the oligosaprobic zone, which is defined as the "zone of cleaner water" where mineralization has been completed (1). However, from the standpoint of sanitation this zone of water is not likely to be clean or pure since it undoubtedly is not free of bacteria and viruses of intestinal origin. The oligosaprobic zone does not have a fixed location nor length since the distance required for stream purification varies according to temperature, the pollution load, the rate of flow, and other factors. The limited flora and fauna of springs and pure mountain streams are placed in a separate group known as the katarobic (1). More extensive lists of organisms considered characteristic of the various pollution zones have been published recently by Butcher (2), Kolkwitz (3), Lackey (4), Liebmann (5), Patrick (6), and others.

Butcher (2) claimed that a community composed of the diatom *Cocconeis* and the blue-green alga *Entophysalis* (listed as *Chamaesiphon*) is present in the portion of the stream which has returned to normal following purification of a polluted condition. Kolkwitz (3) lists as oligosaprobic 61 diatoms, 42 green algae, 41 pigmented flagellates, 23 blue-green algae, and 5 red algae. Lackey (4) found 77 species of planktonic algae in the clean water portion of a small stream, 40 of which were absent in the polluted area a short distance downstream. Liebmann (5) emphasized particularly the following algae as characteristic of the oligosaprobic zone: The flagellate *Chromulina rosanoffi* in slow flowing water, and the flagellate *Mallomonas caudata*, the green algae *Ulothrix zonata* and *Microspora amoena*, and the red algae *Lemanea annulata* and *Batrachospermum vagum* in rapidly flowing water. Patrick (6) listed *Amphora ovalis* and *Gyrosigma attenuatum* as examples of diatoms that seemed to be adversely affected by high organic content of water. Brinley (7) reported that the presence of the flagellate algae *Chrysococcus* and *Cryptomonas* in large numbers indicated that the decomposition of organic matter in the stream has been completed.

Table 8.—Clean Water Algae

Group and Algae	*Plate or Figure*
Blue-Green Algae (Myxophyceae):	
Agmenellum quadriduplicatum, glauca type	4
Calothrix parietina	4
Coccochloris stagnina	4
Entophysalis lemaniae	4
Microcoleus subtorulosus	4
Phormidium inundatum	
Green Algae (Nonmotile Chlorophyceae):	
Ankistrodesmus falcatus, var. acicularis	4
Bulbochaete mirabilis	
Chaetopeltis megalocystis	
Cladophora glomerata	4
Draparnaldia plumosa	
Euastrum oblongum	5
Gloeococcus schroeteri	
Micrasterias truncata	4
Rhizoclonium hieroglyphicum	4
Staurastrum punctulatum	4
Ulothrix aequalis	4
Vaucheria geminata	Fig. 39
Red Algae (Rhodophyceae):	
Batrachospermum vagum	
Hildenbrandia rivularis	4
Lemanea annulata	4
Diatoms (Bacillariophyceae):	
Amphora ovalis	
Cocconeis placentula	4
Cyclotella bodanica	4
Cymbella cesati	
Meridion circulare	4
Navicula exigua var. capitata	
Navicula gracilis	4
Nitzschia linearis	
Pinnularia nobilis	4
Pinnularia subcapitata	
Surirella splendida	4
Synedra acus var. angustissima	
Flagellates (Chrysophyceae, Cryptophyceae, Euglenophyceae and Volvocales of Chlorophyceae):	
Chromulina rosanoffi	4
Chroomonas nordstetii	
Chroomonas setoniensis	
Chrysococcus maior	
Chrysococcus ovalis	
Chrysococcus rufescens	4
Dinobryon stipitatum	
Euglena ehrenbergii	
Euglena spirogyra	
Mallomonas caudata	1
Phacotus lenticularis	4
Phacus longicauda	
Rhodomonas lacustris	4

Some workers have emphasized the relationship of whole groups of algae to pollution in studies involving stream purification. Lackey (8) reported that two classes of algae, the olive-green flagellates, or Cryptophyceae, and the yellow-green flagellates, or Chrysophyceae, appeared to be indicators of clean, unpolluted water. They tended to be present in moderate to great abundance in clean water and reacted adversely to pollution. In another study (4) he observed that all of the Chrysophyceae and most of the Cryptophyceae, Volvocales, and Bacillarieae (diatoms) which were present in clean water were killed in the zone of pollution. Patrick (9) stated that a "healthy" portion of a stream contained algae which are mostly diatoms and green algae. Rafter (10) and other earlier workers assumed that the absence of large amounts of blue-green algae was an indication of clean water.

It is apparent that the lists of clean water algae as reported by various workers include a wide variety of forms belonging to various groups. Some are planktonic while others are epiphytic or attached to rocks and other material on the bottom of the stream.

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CHAPTER VIII

PLANKTON AND OTHER SURFACE WATER ALGAE

THE WATER REQUIREMENTS of growing cities and industry place increasing demands on surface water supplies. Already, the majority of the larger communities are forced to rely primarily on surface rather than ground water. More and more attention must therefore be given to both pollution control and treatment of the water particularly as supplies from less desirable sources have to be tapped (1).

Reservoirs, lakes, rivers, and smaller streams are all normally capable of supporting large mixed groups of aquatic plants and animals. Algae of many kinds are included in this population. In lakes, reservoirs, and large rivers the common forms would be those found especially at or near the surface of the water where light is present in sufficient intensity to permit the algae to carry on their essential process of photosynthesis. The planktonic algae are capable of growing and multiplying while dispersed in the water and unattached to solid objects (2). Many other algae may be carried away from the shore line and from shallow ponds to become mixed with the true planktonic forms or to collect as mats of growth on the surface. Some species of algae are able to develop in abundance at depths of 10, 20, or more feet below the surface.

Recent studies indicate that there are many very minute algae and related organisms present in the water, and that these may often exceed in volume the larger microscopic forms. These very minute forms, are called "nannoplankton," and the smallest of these are generally missed in the routine plankton analysis of water, in which only a low magnification with the compound microscope is used (3). The possible importance of these very small forms has not yet been given much consideration.

The larger unattached algae constitute the bulk of the plankton counts made at many water treatment plants. So long as the total count remains low and no taste-and-odor algae nor filter-clogging forms are present in conspicuous numbers, the waterworks engineer assumes that he is unlikely to have serious difficulties with the algae. A reasonable number of various kinds of common plankton organisms indicates a balanced biological condition in his raw water supply, implying that it will respond to water works treatment with the minimum of trouble. If one group, such as the blue-greens or the diatoms, or one particular species, such as *Anacystis cyanea* (formerly called *Microcystis aeruginosa*) or *Dinobryon divergens*, begins to predominate, then he becomes alert for possible trouble and can treat for the control of algae before undesirable conditions become serious. When blue-green algae become predominant, it frequently indicates either that the water has been enriched with organic matter or that previously there has been a superabundance of diatoms. An understanding of relationships of this sort helps in instituting measures to prevent troublesome growths from developing (4).

In waters poor in nutrients, the factors limiting the number of algae may be the amounts of food materials available, particularly nitrates, phosphates, and, for diatoms, silicates. Some localities are proposing to restrict the algal growths in the raw water supply by removal of phosphate through causing it to precipitate as ferric phosphate. In one of the western cities a problem developed when 20 percent of a ground water containing approximately 5 to 10 p.p.m. nitrogen as nitrate was mixed with a relatively infertile surface supply, causing heavy growths of the green algae, *Golenkinia*, *Palmella*, and *Scenedesmus*. In England, the addition of ground water to a reservoir caused a copious growth of the yellow-green alga, *Tribonema*. The growths of algae in some localities have been so rank as to necessitate withdrawing the reservoir from service. Many bodies of water are sufficiently rich in the essential nutrients that these nutrients do not become limiting factors in determining the abundance of algae. Other factors such as turbidity, water temperature, and parasitism may be the critical ones. Although it is assumed that the chemical and physical environment largely determines the amount of algal production, the exact relationships remain in many respects obscure.

BLOOMS

A number of the surface water algae have the ability to accumulate, at times, in such numbers as to form loose, visible aggregations called "blooms," which may cover very large areas of lakes and reservoirs or even streams. Blue-green algae may form these water blooms particularly during periods of warm, calm weather, when the algae which previously were distributed through the water rise to the surface. Other blooms may be associated with a rapid reproduction of a particular alga. Some water blooms have resulted in fish kills by interfering with reaeration, by excluding light necessary for photosynthesis in the lower areas and thereby preventing release of oxygen into the water, or by depleting the oxygen through decay or respiration within the bloom. Some water blooms release substances extremely toxic to fish, domestic animals, and birds, and extensive kills have resulted in several areas (5).

A considerable number of species of algae are capable of producing blooms. Some of the genera most frequently involved are the blue-green algae, *Anacystis* (*Microcystis*), *Anabaena*, *Aphanizomenon*, and *Oscillatoria;* the green algae, *Hydrodictyon*, *Chlorella*, and *Ankistrodesmus* (fig. 35);

the diatoms, *Synedra* and *Cyclotella;* and the flagellates, *Synura*, *Euglena*, and *Chlamydomonas*. Blooms of blue-green algae are particularly obnoxious. Blooms of flagellates and green algae are often encouraged by the addition of fertilizer in farm hatchery ponds in order to increase fish production (6).

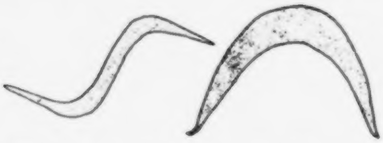

Figure 35.—*Ankistrodesmus falcatus.*

Related to the blooms, are the "mats" or "blankets" (fig. 36) of filamentous green algae such as *Spirogyra*, *Zygnema*, *Oedogonium*, and *Cladophora* which at times may cover large areas of a reservoir or lake (7). Certain blue-green algae, such as *Gloeotrichia natans* (fig. 37) may also form extensive floating masses. These growths cause an unsightly appearance in a community's water supply and serve as breeding places for gnats and midge flies. They may clog intake screens, cause tastes and odors, and interfere with the functioning of multiple purpose reservoirs by collecting as debris on the shores and interfering with fishing and bathing. Many of the mat-forming algae are resistant to effective treatment with copper sulfate. Frequent inspections of raw water supplies for detection of the visible growths, together with routine microscopic analyses of water samples are necessary if the various kinds of algae are to be effectively controlled.

The list of surface water algae covered in the manual is given in table 9. It is more extensive than for the other groups and includes a total of 68 species with 22 illustrated in color on plate 5. Many of the species on the other lists in this manual could also be considered as prominent members of the flora of surface waters. Additional species would also need to be added to make the list fairly representative for any particular locality. Since the total number of known species of algae is several thousand, it is obviously not possible to include here all of even the common forms. Transeau (8) lists, for example, 275 species of the genus, *Spirogyra;* Hustedt (9) describes more than 125 species belonging to the genus, *Navicula;* and Gojdics (10) recognizes 155 species of *Euglena*.

It is emphasized that not all of the algae in the list of surface water forms are planktonic. The list includes algae which may be originally benthic (attached and bottom-dwelling) forms but are frequently swept away into the open water.

Figure 36.—A surface blanket of filamentous algae.

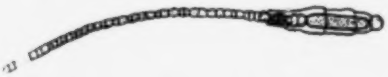

Figure 37.—*Gloeotrichia natans*.

The open water algae have several mechanisms which aid in keeping them dispersed in the water and retard any tendency toward settling out. The pigmented flagellates, represented on plate 5 by *Euglena*, *Phacus*, *Gonium*, and *Eudorina*, are swimming forms with whip-like flagella which apparently aid in the forward movement of the cells through the water. Spines or the spine-like shapes of entire cells help to keep certain nonswimming green algae, such as *Actinastrum*, *Micractinium*, and *Scenedesmus*, suspended in the water. The large flat surfaces exposed to the water do the same thing for the diatoms *Fragilaria* and *Tabellaria*, and the green alga, *Pediastrum*. A number of planktonic blue-green algae have internal "gas vacuoles" which help to keep the cells afloat.

Various shapes are found among the surface water algae. Spherical or sub-spherical colonies of cells are found in *Coelastrum*, *Oocystis*, *Gomphosphaeria*, and *Sphaerocystis*. Filamentous forms include *Nodularia*, *Mougeotia*, *Zygnema*, *Cylindrospermum*, *Melosira*, and *Desmidium*. The diatoms *Stauroneis* and *Navicula* are boat-shaped and capable of moving through the water. The odd-colored *Botryococcus* with its green cells embedded in a brownish mucilaginous sheath is often irregular in form and surface.

From their specialties in shape and internal structure, many of the algae can be recognized readily under the microscope (fig. 38). This makes possible, in the routine microscopic analysis of water samples, a record of the presence and abundance of many of the significant species. Several helpful books have been published recently, giving lists, keys, descriptions, and illustrations of the algal flora of particular States or regions. Examples of these are the algae of Illinois (11), algae of Tennessee (12), algae of the western Great Lakes area (13), and the algae of the United States (14). Available information of this character will facilitate the accurate recording of the algae found in streams, lakes, and reservoirs which are being used as the water supply for an ever-increasing number of cities, towns, and industrial establishments.

Each year a seasonal cycle is evident in the plankton population of lakes and reservoirs. Diatoms generally increase in number in late winter, often with two or three additional pulses occurring during the spring months. In early summer, the green algae are likely to be abundant followed in the late summer and early autumn by an increased growth of blue-greens. Then there will follow a late autumn maximum of diatoms. Throughout most of the winter the diatoms and certain other algae may remain in the water but with little or no increase in numbers until conditions, in the late winter, stimulate the organisms to begin the cycle all over again. Various brown and green flagellates and the yellow-green alga *Tribonema* occasionally appear in the cycle as abundant growth for brief periods, the time of year depending in part upon the particular species involved.

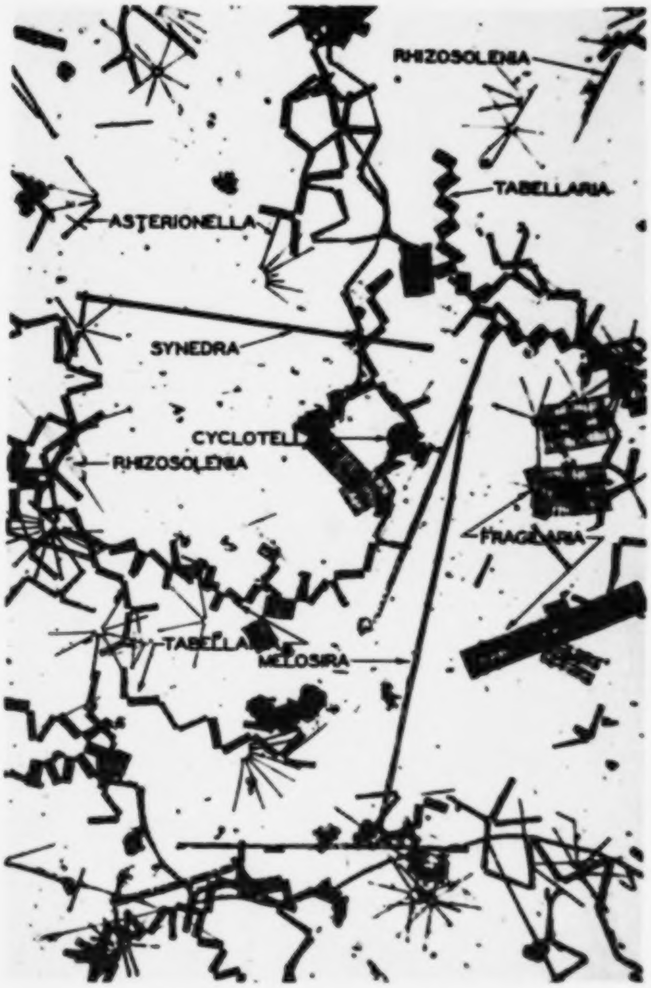

Figure 38.—Plankton diatoms, showing distinctive shapes of cells and colonies. The relative sizes of the various organisms are also evident in this composite photomicrograph which was furnished by J. R. Baylis, Engineer of Water Purification, Department of Water and Sewers, Bureau of Water, Chicago, Ill.

When records are kept for a long period of time of the phytoplankton present in a reservoir or lake, they often reveal that certain genera and species are predominant year after year. In one metropolitan district (15) the reservoirs contained enormous numbers of *Tabellaria* and *Ceratium* with an abundance also of *Asterionella*, *Fragilaria*, *Synedra*, *Cyclotella*, *Dinobryon*, and *Pandorina*. Over a period of approximately 40 years, however, there was a gradual change in the predominant algae. *Tabellaria* dropped out completely and new forms appeared, chiefly *Stephanodiscus astraea* and *Stephanodiscus hantzschii*, together with several filamentous blue-green algae.

Table 9.—Plankton and Other Surface Water Algae

Group and algae	*Plate or Figure*
Blue-Green Algae (Myxophyceae):	
Anacystis thermalis	
Cylindrospermum stagnale	5
Gloeotrichia natans	Fig. 37
Gomphosphaeria aponina	5
Gomphosphaeria lacustris, collinsii type	
Gomphosphaeria wichurae	
Lyngbya versicolor	
Nodularia spumigena	5
Nostoc carneum	
Oscillatoria agardhii	
Phormidium retzii	
Plectonema tomasiniana	
Scytonema tolypothricoides	
Spirulina nordstedtii	
Filamentous Green Algae (of Chlorophyceae and Chrysophyceae):	
Cladophora fracta	
Desmidium grevillei	5
Hyalotheca mucosa	
Mougeotia genuflexa	
Mougeotia scalaris	5
Oedogonium idioandrosporum	
Spirogyra fluviatilis	
Spirogyra varians	Fig. 36
Stigeoclonium stagnatile	
Tribonema minus	
Ulothrix tenerrima	
Vaucheria terrestris	
Zygnema pectinatum	
Zygnema sterile	5
Nonfilamentous, Non-Motile Green Algae (of Chlorophyceae):	
Actinastrum gracillimum	5
Actinastrum hantzschii	
Ankistrodesmus falcatus	Fig. 34
Botryococcus braunii	5
Chlorella ellipsoidea	
Closterium aciculare	
Coelastrum microporum	5
Cosmarium botrytis	
Crucigenia quadrata	
Dimorphococcus lunatus	
Euastrum oblongum	5
Kirchneriella lunaris	
Micractinium pusillum	5
Oocystis borgei	5
Ophiocytium capitatum	
Pediastrum boryanum	5
Pediastrum duplex	Fig. 38
Scenedesmus bijuga	
Scenedesmus dimorphus	
Scenedesmus quadricauda	5
Schroederia setigera	
Selenastrum gracile	
Sphaerocystis schroeteri	5
Staurastrum polymorphum	
Diatoms (Bacillariophyceae):	
Cyclotella glomerata	
Cymatopleura solea	
Fragilaria capucina	5
Gyrosigma attenuatum	
Melosira crenulata	
Navicula radiosa	
Rhizosolenia gracillis	
Rhopalodia gibba	
Stauroneis phoenicenteron	5
Stephanodiscus hantzschii	5
Synedra capitata	
Flagellates (Chrysophyceae, Euglenophyceae, and Volvocales of Chlorophyceae):	
Dinobryon sociale	
Eudorina elegans	5
Euglena gracilis	5
Gonium pectorale	5
Phacus pleuronectes	5

Although many environmental factors are relatively constant for any body of water and tend to keep the phytoplankton population stable, other factors will change sufficiently to influence the growth and relative abundance of the various genera and species comprising the flora.

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CHAPTER IX

ALGAE ATTACHED TO RESERVOIR WALLS

MANY of the algae which grow attached to some substrate are large and conspicuous, often covering a considerable area and extending several inches into the water. Those of importance in water supplies may grow not only in the stream, lake, and reservoir, but in the treatment plant itself. These algae are commonly found attached to such objects as the wet concrete walls of settling basins, the screens at the ends of the intake pipes, and the wood, brick, stone riprap, or even soil surfaces of reservoir walls and bottoms. Many are abundant in streams where they may be attached to submerged twigs or rock and other materials forming the stream bed.

In small amounts these algae are not a cause for alarm, but when abundant they may become a decided nuisance. They may clog screens to which they are attached, and reduce the flow in canals by the amount of space they occupy and the increased friction of their surfaces. In multiple-purpose lakes and reservoirs, they often interfere with swimming and fishing or develop such rank growths in the shallow margins that they are the cause of constant complaints from nearby residents. In addition, they may break away from their attachments to form unsightly surface mats, clog screens and filters, or produce offensive odors in the air and water. Other smaller algal forms may produce a continuous slimy and slippery layer on concrete or other surfaces, which in swimming pools is undesirable or even dangerous.

The attached algae considered here number 42 species, listed under their respective groups in table 10; 21 are illustrated in color on plate 6. Included are diatoms, blue-green, green, and fresh-water red algae, but no flagellates. Many of these algae grow in the form of unbranched or branched filaments or tubes and are fastened at one end to the substrate by means of a special anchoring device. *Vaucheria* is a branched, tubular form with several common species (figs. 39, 40). Typical branching filamentous green algae are *Cladophora*, *Pithophora* (fig. 41), *Chaetophora*, *Stigeoclonium*, *Draparnaldia*, *Bulbochaete*, *Chara*, and *Nitella*. The species *Cladophora glomerata* is a very common attached alga in rapidly flowing water and is considered the most abundant filamentous alga in streams throughout the world (1). Nonbranching filamentous green algae include *Oedogonium*, *Microspora*, and *Ulothrix* and the more complex *Schizomeris* (fig. 42). The genera, *Audouinella* (formerly called *Chantransia*), *Batrachospermum*, and *Compsopogon* are fresh-water red algae, the last one being common in the Southern States. Some filamentous blue-green algae such as *Phormidium*, *Lyngbya*, *Tolypothrix*, and *Stigonema* (fig. 43) form dense mats, one side of which is exposed and the other side attached to the substrate.

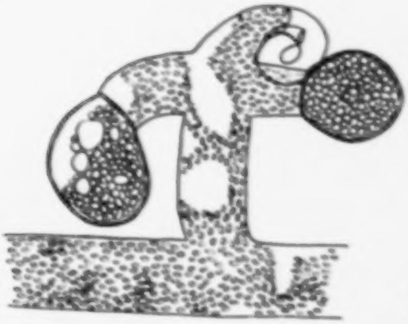

Figure 39.—*Vaucheria geminata*.

Some diatoms, such as *Achnanthes*, *Gomphonema*, and *Cymbella* are attached to surfaces by gelatinous stalks or tubes. In Australia, *Gomphonema* developed as an extensive growth and formed a slippery, felt-like mat covering the cement walls of an aqueduct for several miles (2). The species of *Cymbella* which grows inside a hollow tube, as illustrated on plate 6, has sometimes been placed in a separate genus, *Encyonema* (3).

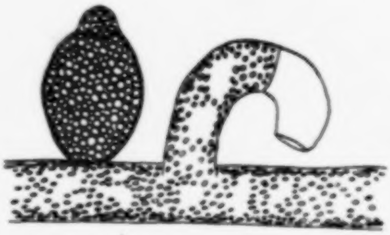

Figure 40.—*Vaucheria sessilis*.

A white marble surface serving as the floor of an observation well in one water treatment plant became overgrown with a continuous brown layer of *Achnanthes*. The observation well was located on a conduit carrying water from sand filters to the clear well. The marble surface was brushed clean but the color returned again within 2 weeks. After a second cleaning, electric lights that had been left on continuously at the bottom of the observation well were then turned off excepting for brief times when needed for display. The brown color did not return because the diatoms were not capable of developing in darkness.

The green alga, *Phytoconis* (formerly called *Protococcus*) is common as a thin green layer on the surface of moist wood and bark above the water line, but it is seldom found submerged. Another green alga, *Tetraspora* (fig. 44), is composed of minute rounded cells in a soft, fragile, mucilaginous, common tube which is attached at one end to the substrate. It is one of the first algae to develop in abundance in the cold water of streams and pools after the ice melts in early spring.

In reservoirs and lakes having rocky rather than sandy shores, *Cladophora* and other large filamentous algae often develop during the summer as extensive massive growths. When this material becomes detached by wave action and is thrown up on the shore, it may require immediate removal to prevent the development of septic odors (4).

Drastic measures often have to be taken to control the attached algae, especially if the growths are neglected until large quantities threaten to cause trouble. One city adapted a floor-cleaning machine, fitted with a cylindrical wire brush, for use in scraping the algal growth from the concrete floor of a 13 million gallon reservoir. The machine proved to be much more effective than hand scrapers in removing the attached portions of the algae from the more than 100,000 square feet of concrete. The detached algae were then flushed from the reservoir floor by streams of water from a fire hose (5). The use of chemicals to kill attached algae when they are present in quantity may not solve the

Table 10.—Algae Attached to Reservoir Walls

Group and algae	*Plate or Figure*
Blue-Green Algae (Myxophyceae):	
Calothrix braunii	
Lyngbya lagerheimii	6
Lyngbya ocracea	
Nostoc pruniforme	
Oscillatoria tenuis	Fig. 30
Phormidium retzii	
Phormidium uncinatum	6
Stigonema minutum	
Tolypothrix tenuis	6
Green Algae (Nonmotile Chlorophyceae, Charophyceae):	
Bulbochaete insignis	6
Chaetophora attenuata	
Chaetophora elegans	6
Chara globularis	6
Cladophora crispata	6
Cladophora glomerata	4
Draparnaldia glomerata	6
Gloeocystis gigas	
Microspora amoena	6
Nitella flexilis	
Oedogonium boscii	
Oedogonium grande	
Oedogonium suecicum	6
Palmella mucosa	2
Phytoconis botryoides	6
Pithophora oedogonia	Fig. 41
Rhizoclonium hieroglyphicum	4
Schizomeris leibleinii	Fig. 42
Stigeoclonium lubricum	6
Tetraspora gelatinosa	6
Ulothrix zonata	6
Vaucheria geminata	Fig. 39
Vaucheria sessilis	6
Red Algae (Rhodophyceae):	
Audouinella violacea	6
Batrachospermum moniliforme	6
Compsopogon coeruleus	6
Diatoms (Bacillariophyceae):	
Achnanthes microcephala	6
Cocconeis pediculus	
Cymbella prostrata	6
Epithemia turgida	
Gomphonema geminatum	6
Gomphonema olivaceum	
Rhoicosphenia curvata	

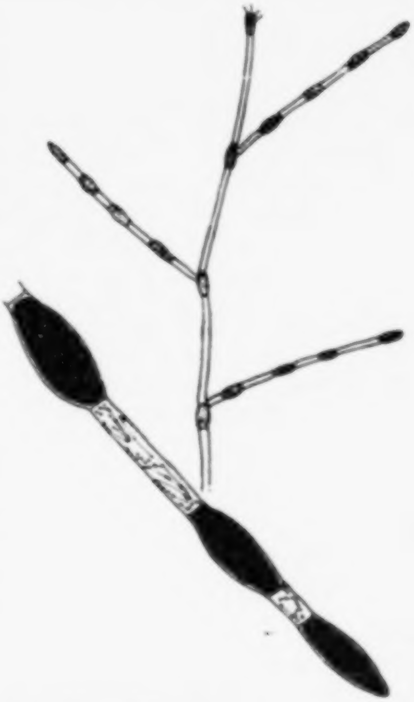

Figure 41.—*Pithophora oedogonia.*

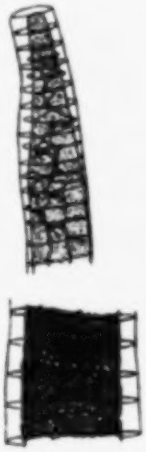

Figure 42.—*Schizomeris leibleinii.*

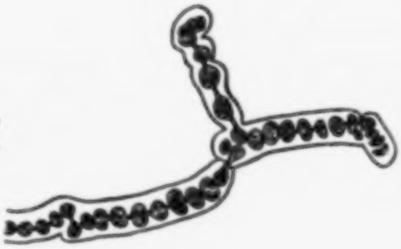

Figure 43.—*Stigonema hormoides.*

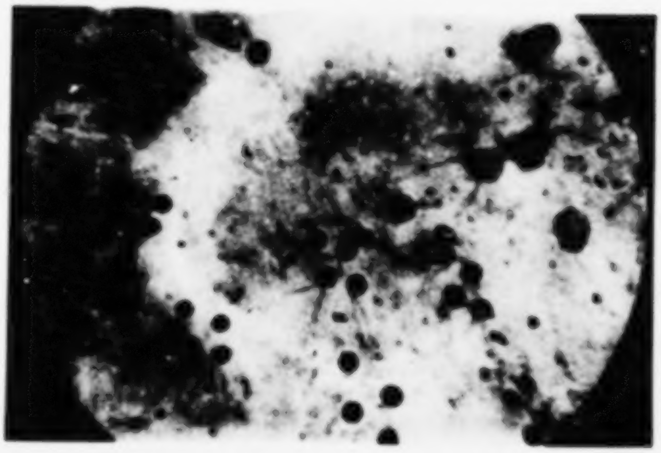

Figure 44.—*Tetraspora.* Portion of colony showing cells grouped in fours. Pseudocilia are barely visible on a few of the cells.

problem because dead algae as well as living ones can clog filters and screens, release slimes into the water, and cause tastes and odors.

In areas in the western part of the country where there are extensive systems of canals for irrigation farming, massive growths of attached algae, together with certain aquatic flowering plants, constitute a serious problem. Because of their bulk, they impede the flow of water through the ditches and clog the control gates and the distribution lines. *Cladophora* and *Rhizoclonium* are by far the most important algae encountered. The peak of their development is generally in the spring after which they often become inconspicuous during the summer, with new growth beginning in the autumn. The green alga *Enteromorpha*, commonly thought of as a brackish water form, may become abundant during the summer, and the fresh-water red alga, *Compsopogon*, may flourish during the autumn. One common method of control has been the mechanical removal of the algae by means of chains or scrapers that are pulled along the canals by tractors. Four irrigation districts in Arizona spend a total of approximately $250,000 annually to control this growth (6).

Attached algae are present and apparently significant in the trickling filters of sewage treatment plants. They form a large part of the population of microorganisms growing in a layer around the stones of the filter. The exposed surface of the layer is predominantly fungal, the intermediate portion is predominantly algal, and the basal portion, against the stone, is a fungal, algal, and bacterial mixture. The layer may reach a thickness of 1 to 2 mm. The attached alga most frequently encountered is *Stigeoclonium*. In addition to its branching filaments it also develops as a basal, attached, irregular tight mat of cells which strongly resembles a colony of the nonfilamentous green alga *Chlorococcum*. The branching filaments of *Stigeoclonium* rise from this basal mat. Species of attached algae from the trickling filters of one treatment plant (7) were reported as *Stigeoclonium nanum*, *Ulothrix tenuissima*, *Phormidium uncinatum*, *Amphithrix janthina* and *Characium* sp. Other algae commonly mixed with the attached forms were *Scenedesmus bijuga*, *Oocystis parva*, *Chlorella vulgaris*, *Chlamydomonas*, *Nitzschia palea* and *Anacystis montana*.

Consideration is being given to the use of attached algae in tertiary treatment of sewage effluents. In addition the algal growth might be harvested and prepared for use as fertilizer, mulch, cattle feed, etc. The attached forms would not present the difficulty of harvesting that is encountered with plankton organisms.

Thus it is evident that the attached algae may produce undesirable conditions or be put to good use depending upon the particular locations and conditions in which they develop.

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CHAPTER X

ADDITIONAL PROBLEMS CAUSED BY ALGAE IN WATER SUPPLIES

THE WIDESPREAD distribution of algae in water supplies, together with their unique combination of characteristics, allows them to exert effects in many places and in many ways. In addition to those activities discussed in the preceding six chapters, the algae have been implicated in production of slime in industrial water supplies, causing coloration of water, inducing corrosion of concrete and of metals, reducing the potability of treated water by their presence in distribution systems, interfering with the chemical treatment of water, and causing illness in man and animals (1).

SLIME

Slime formation in water can be caused or aided by various kinds of algae, bacteria, and other organisms (2). Slime-producing algae are important in open reservoirs and in uncovered holding basins of recirculating systems. They can become a serious problem especially in the water supplies for pulp mills and food industries by causing slime spots or masses in the products. Coatings of slime may also develop on condenser tubes in industrial cooling systems and have the effect of reducing the rate of heat transfer to the water (3). Slime accumulation in the unlighted portions of distribution systems may be due to bacteria, to the tardy settling out of the coagulant, or to other agents, but not to algae.

Algal slime commonly is derived from the mucilaginous capsule or sheath which envelops the cells. The blue-green algae as a group are notorious slime producers. Their technical name, Myxophyceae, contains the prefix "myxo" which means slime or mucus. Several diatoms as well as green and red algae and a few flagellates also produce slimy sheaths or capsules. A few of the slime-forming algae are given in table 11.

COLORATION

Algal coloration of finished water is most frequent in communities that have uncovered storage reservoirs in the distribution system, or where the treatment of the raw water supply is not efficient in reducing the numbers of phytoplankton present. Almost any small alga capable of rapid multiplication could be involved. Complaints come from patrons when the water from the faucet is colored, or when a colored marginal ring forms at the surface of the water in the tumbler or bathtub. Colors ranging from yellow-green through green, blue-green, red, and brown to black could all be due to algae. In table 11 are listed some of the algae that have been implicated. However, colors in water may also be caused by substances other than algae.

CORROSION

Corrosion of concrete and of metals in pipes and boilers is a continual problem. Algae sometimes contribute to corrosion either directly in localized places where they may be growing or through their modification of the water by physical or chemical changes. Green and blue-green algae, along with lichens and mosses growing on the surface of submerged concrete, have caused the concrete to become pitted and friable. The effect was most pronounced when the percentage of SO_3 in the mortar was 0.6 or higher. Some of the algae associated with this change are given in table 11. It is assumed that the gelatin present in the living plants together with the carbonic, oxalic, and silicic acids produced by them are adequate to corrode the cement (4).

Typical algae are unlikely to be the direct cause of corrosion of iron or steel pipes in a distribution system because most are incapable of active growth in the absence of light. However, algae have been reported to cause corrosion in metal tanks or basins open to sunlight. *Oscillatoria* growing in abundance in water in an open steel tank has caused serious pitting of the metal. The pits were bright and clean because the iron was apparently going into solution and not producing any covering compound such as an oxide or sulfide. The algal growth permitted the pitting to take place by releasing oxygen which combined with the protecting film of oxide over the steel. When the steel tank was covered to prevent entrance of light, the algae disappeared and the corrosion stopped (5).

Indirectly, algae may affect the rate of corrosion in a number of ways. Increase in organic deposits in the pipe, increase in the dissolved oxygen in the water through photosynthesis in the raw water supply, and changes in the pH, CO_2 content, and calcium carbonate content of the water can all be brought about by algae. These changes can, in turn, affect the rate of corrosion. Iron and sulfur bacteria may have a more direct relationship to corrosion and may be significant particularly on the outside surfaces of pipe buried in the ground.

ALGAE IN TREATED WATERS

The persistence of algae in the water of distribution systems tends to become more pronounced as additional surface water supplies are tapped, but less evident as effective measures for reducing the plankton in the water are practiced. As most algae cannot grow and multiply without light, the only algae which would be encountered in the pipes of the distribution system would be first those not removed in the treatment process; second, the few algae unusual in their ability to grow in the dark; and third, those that develop in an uncovered reservoir containing treated water. The algae capable of growth in the dark include some species of *Scenedesmus*, *Euglena*, *Anacystis*, *Coelastrum*, and *Chlorococcum*.

Since the treated water in most distribution systems has a free chlorine residual, the algae most likely to remain intact in the pipelines would be the chlorine-resistant forms. These algae might be capable of carrying into the distribution system living bacteria, presumably even pathogenic forms, which are protected from the lethal effect of the chlorine by being embedded in the gelatinous covering surrounding the algal cells (6). Algae reported to be resistant to chlorine in distribution systems include *Elaktothrix gelatinosa*, *Gomphosphaeria aponina*, *Closterium* (fig. 45), *Cosmarium*, and *Chlorella*. In one water supply receiving a normal chlorine treatment but no coagulation or filtration, counts of up to 2,200 algae per ml. were recorded for the tap water.

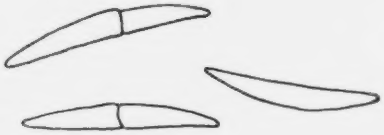

Figure 45.—*Closterium lunula*, a desmid.

Table 11.—Additional Problems Caused by Algae in Water Supplies

Problem and algae	*Color of water*	*Algal group*
Slime-producing Algae:		
Anacystis (Aphanocapsa, Gloeocapsa)		Blue-green
Batrachospermum		Red
Chaetophora		Green
Cymbella		Diatom
Euglena sanguinea var. furcata		Flagellate
Euglena velata		Flagellate
Gloeotrichia		Blue-green
Gomphonema		Diatom
Oscillatoria		Blue-green
Palmella		Green
Phormidium		Blue-green
Spirogyra		Green
Tetraspora		Green
Algae Causing Coloration of Water:		
Anacystis	Blue-green	Blue-green
Ceratium	Rusty brown	Flagellate
Chlamydomonas	Green	Flagellate
Chlorella	Green	Green
Cosmarium	Green	Green
Euglena orientalis	Red	Flagellate
Euglena rubra	Red	Flagellate
Euglena sanguinea	Red	Flagellate
Oscillatoria prolifica	Purple	Blue-green
Oscillatoria rubescens	Red	Blue-green
Algae Causing Corrosion of Concrete:		
Anacystis (Chroococcus)		Blue-green
Chaetophora		Green
Diatoma		Diatom
Euglena		Flagellate
Phormidium		Blue-green
Phytoconis (Protococcus)		Green
Algae Causing Corrosion of Steel:		
Oscillatoria		Blue-green
Algae Persistent in Distribution Systems:		
Anacystis		Blue-green
Asterionella		Diatom
Chlorella		Green
Chlorococcum		Green
Closterium		Green
Coelastrum		Green
Cosmarium		Green
Cyclotella		Diatom
Dinobryon		Flagellate
Elaktothrix gelatinosa		Green
Epithemia		Diatom
Euglena		Flagellate
Gomphosphaeria aponina		Blue-green
Scenedesmus		Green
Synedra		Diatom
Algae Interfering With Coagulation:		
Anabaena		Blue-green
Asterionella		Diatom
Euglena		Flagellate
Gomphosphaeria		Blue-green
Synedra		Diatom
Algae Causing Natural Softening of Water:		
Anabaena		Blue-green
Aphanizomenon		Blue-green
Cosmarium		Green
Scenedesmus		Green
Synedra		Diatom
Toxic Marine Algae:		
Caulerpa serrulata		Green
Egregia laevigata		Brown
Gelidium cartilagineum var. robustum		Red
Gonyaulax catenella		Dinoflagellate
Gonyaulax polyedra		Dinoflagellate
Gonyaulax tamarensis		Dinoflagellate
Gymnodinium brevis		Dinoflagellate
Gymnodinium veneficum		Dinoflagellate
Hesperophycus harveyanus		Brown
Hornellia marina		Flagellate
Lyngbya aestuarii		Blue-green
Lyngbya majuscula		Blue-green
Macrocystis pyrifera		Brown
Pelvetia fastigiata		Brown
Prymnesium parvum		Flagellate
Pyrodinium phoneus		Dinoflagellate
Trichodesmium erythraeum		Blue-green
Toxic Fresh-water Algae:		
Anabaena		Blue-green
Anabaena circinalis		Blue-green
Anabaena flos-aquae		Blue-green
Anabaena lemmermanni		Blue-green
Anacystis (Microcystis)		Blue-green
Anacystis cyanea (Microcystis aeruginosa)		Blue-green
Anacystis cyanea (Microcystis flos-aquae)		Blue-green
Anacystis cyanea (Microcystis toxica)		Blue-green
Aphanizomenon flos-aquae		Blue-green
Gloeotrichia echinulata		Blue-green
Gomphosphaeria lacustris (Coelosphaerium kuetzingianum)		Blue-green
Lyngbya contorta		Blue-green
Nodularia spumigena		Blue-green
Parasitic Aquatic Algae:		
Oodinium limneticum		Dinoflagellate
Oodinium ocellatum		Dinoflagellate

In the counting, no distinction was made between living and dead organisms. Some of the most abundant genera were *Asterionella*, *Cyclotella*, *Dinobryon*, *and Synedra* (7).

Reservoirs in the distribution system can be provided with covers to keep out the sunlight and thus prevent the growth of algae. Ground waters stored in open reservoirs are often more susceptible to prolific algal growths than are treated surface waters, possibly because their lower turbidity permits greater light penetration. The ground waters usually contain in solution a supply of nitrates, phosphates, iron, silica, and carbonic acid in quantities sufficient to support the phytoplankton and especially the diatoms. The ground water is easily seeded with algae and other organisms which may be carried to the reservoir by the wind or on the bodies of aquatic birds. The algae can impart their characteristic odors to the stored water and these can be carried into the remainder of the distribution system (8).

Algae that persist in distribution systems can increase the organic content of the water sufficiently to deplete the residual chlorine in the water. In addition, this organic content may feed bacteria, blood worms, nematodes, copepods, fresh-water sponges, bryozoa, and other undesirable organisms. Organisms that grow attached to the inner surface of the pipes are commonly known as "pipe moss."

ROLE OF ALGAE IN WATER TREATMENT PROBLEMS

Interference by algae with the chemical treatment of water can be due to the changes they cause in pH, alkalinity, total hardness, and dissolved oxygen (D.O.) of the raw water, or to their increasing of the organic content carried by the water. It may be necessary, for example, to vary the dosage of chlorine in direct proportion to the quantity of algae present in order to obtain a constant amount of residual chlorine in the water.

In the clarification of water it is necessary to treat water with a coagulant aid in addition to the coagulant if the raw water has a low plankton population and low turbidity due to silt or other particles. The aid may be finely divided clay, bentonite, fuller's earth, activated carbon, or similar materials composed of finely divided insoluble particles. The addition of a small amount of the aid will furnish particles which act as centers for the formation of the floc. *Asterionella* and *Synedra* have been reported as inhibiting proper floc formation (9). While it is possible that these particular kinds of algae might give more difficulty than others during coagulation and sedimentation, the total volume of all the algae is apparently more important. Sedimentation alone would permit dead algae to settle out gradually along with clay and other inorganic particles present. The living planktonic algae would tend to remain distributed throughout the water in the absence of a coagulant.

Many industrial establishments require a water with narrow ranges of variation in physical and chemical characteristics. In one Connecticut city (10) the felting and dyeing processes are a part of the major industries, and they require a water free of color, turbidity, iron and aluminum and with low and constant pH and hardness. The city water treatment plant is charged with the responsibility of supplying water satisfactory for the city's industries. The raw water supply comes from reservoirs which support populations of algae that change in concentration from day to day. As this change occurs, small daily adjustments in chemical feed, equipment and operational methods are made in the water treatment plant in order to maintain the predetermined optimum conditions such as turbidity of not more than 2.0 on the filters, minimum filter runs of 23 hours, maximum pH of 6.7 in the treated water, minimum rates of flow of 70,000 gallons per foot head loss per filter, and minimum floc size in the last flocculator of 2.0 mm.

Normally a large floc particle is obtained quickly and without agitation. Agitators are used, however, when certain free floating algae, particularly *Gomphosphaeria* and *Anabaena*, are abundant. The agitation causes smaller floc particles to be formed which in this situation gives a settled water with lower turbidity and color than would be obtained with large floc particles.

Daily blooming of algae in the reservoirs frequently induces the formation of a weak floc during coagulation in the treatment plant and allows appreciable amounts of undesired substances to remain in the water and to pass through the sand filters into the finished water. The blooming of the algae may cause the pH of the raw water to rise from 7.0 to 10.0 in a few hours. It is the high pH which causes a poor floc to be formed when alum is added. Formerly the importance of algae in causing this change was not recognized, and treatment plant operators were continually puzzled by the sudden inexplicable shift to a settled water of poor quality. During the high peak of the pH cycle the normal amount of alum which they had added to the water was insufficient to lower the pH to the point where good floc formation would occur.

In some cases, the pH of the finished water is adjusted to be within a desired range for industry by the addition of acid or alkali. The water for a certain steel mill requires approximately 800 pounds of 60 percent H_2SO_4 per day to keep the pH of the water down to 8 as it is drawn from a 320-acre lake. The algae in this lake are responsible for increases in the pH of the water, and regular phytoplankton counts are made as an aid in estimating the amount of change in pH which will occur.

In another state a reservoir of 350 acres had a total hardness normally of 120 p.p.m. In early June of one year this suddenly dropped to 90 p.p.m. The D.O. increased from 8.3 to 13.0 p.p.m.; the pH, from 8.6 to 8.9; the carbonate alkalinity from 20 to 30 p.p.m; and the turbidity from 9 to 18 p.p.m. At the same time the blue-green alga, *Anabaena*, which was then the dominant form, increased from 750 to 4,730 areal standard units per ml. Favorable conditions were created for the precipitation of calcium carbonate and thus a softening of the water. According to the report, the many cells of *Anabaena* had utilized sufficient "half-bound" carbon dioxide in their metabolism to increase the pH, which in turn made possible the precipitation of the calcium carbonate (11). Other algae have been observed to bring about a similar change. These are listed in table 11. British experience has shown that vigorous algal growths of many kinds can reduce water hardness by as much as one-third (12).

TOXICITY OF ALGAE

Illness in man and animals has been attributed to both marine and fresh-water algae. A toxic agent produced by the marine armored flagellate *Gonyaulax* (13) can cause serious illness in man following eating of clams that have fed on particular species of this genus. The poison has been described as a toxin 10 times as potent for mice as strychnine. *Gonyaulax* and *Gymnodinium*, another armored flagellate may accumulate in very large numbers in ocean water near the shore and produce a condition known as "red tide," "red water," or "yellow-green peril." These flagellate blooms have been reported for a number of localities throughout the world, including the coasts of California, Florida, and Texas, as well as Peru, Japan, Australia, India, Africa and Europe. Shellfish poisoning due to *Gonyaulax* has also been reported for Quebec, Nova Scotia, New Brunswick, and Vancouver Island in Canada, and for California, Alaska, Oregon, Maine, Mexico, British Isles, Norway, France, Belgium, and New Zealand (14, 15).

Many kinds of fish and other marine animals are often killed during the time of the red tide but perhaps as the result of other factors than the toxin since according to some workers the poison has little or no effect on fish. When the decaying fish are washed up on the beaches, the stench and the need for quick disposal constitute a serious problem for the communities affected. *Gymnodinium veneficum*, a species related to red tide algae, has been found to kill fish in a short time and is lethal also to shell fish, arthropods and echinoderms (16).

Several other marine algae have been implicated as causing reef fishes to be poisonous in some areas. Large numbers of poisonous fishes are known to be herbivorous, and considerable evidence exists to indicate that these fish are poisonous as food only after they have fed on certain kinds of algae (17). In a large majority of the poisonous fishes that were examined, the blue-green alga *Lyngbya* (fig. 46) was detected in the alimentary tract. *Lyngbya majuscula* and *Lyngbya aestuarii* were the common species in the area and in the fish samples. It is interesting to find a report published in 1904 that "numbers of horses have frequently been killed by feeding on *Lyngbya majuscula* which occurs in abundance on the coral beaches in the Gulf of Manor" along the coast of India (18). Other marine algae have been found toxic to mice, but their possible toxicity to man has not been determined (19). An algal flagellate, *Prymnesium parvum*, reported for Europe and common in brackish water ponds in Israel, produces an extracellular toxin which has resulted in mass mortality among fishes and in Israel is considered the most serious natural obtacle to fish breeding (20).

Toxic fresh-water algae affecting man have been reported in the United States and elsewhere. Contact type dermatitis and symptoms of "hay fever" have been reported to be caused by blue-green algae. *Anabaena* was implicated in the former reaction (21) while *Anacystis* (*Microcystis*) and *Lyngbya contorta* were listed for the latter (22). In a few cases the green alga *Chlorella* has been found associated with fungi in mycotic lesions in man, but its significance has not been determined (23). Unexplained outbreaks of gastroenteritis involving thousands of people, and possibly related to the water supplies, have been reported in the same areas where extensive algal blooms were present (24). However, any direct relationship between the algal blooms and the intestinal disorders in humans has not been clearly demonstrated (25). It has been suggested as a possibility that the disintegration of large amounts of blue-green algae on the sand filters of water treatment plants and the passage of toxic products into the distribution mains may be the cause of the gastro-intestinal disturbances (26).

There are many records of acute and often fatal poisoning of livestock where the animals had been drinking from ponds containing dense algal blooms (27). Animals affected have included horses, cattle, hogs, sheep, dogs, rabbits, and poultry. In all cases the algae implicated as the toxic agents are blue-greens, *Anacystis* (*Microcystis*) being the genus most often involved. The first alga reported as toxic was *Nodularia spumigena* (fig. 47). The several genera and species which are reported as toxic are listed in table 11. Areas which have reported poisoning of animals, presumably due to algal blooms, include Colorado, Idaho, Iowa, Michigan, Minnesota, Montana, North Dakota, South Dakota, Wisconsin, and Alberta, Ontario, Bermuda, Argentina,

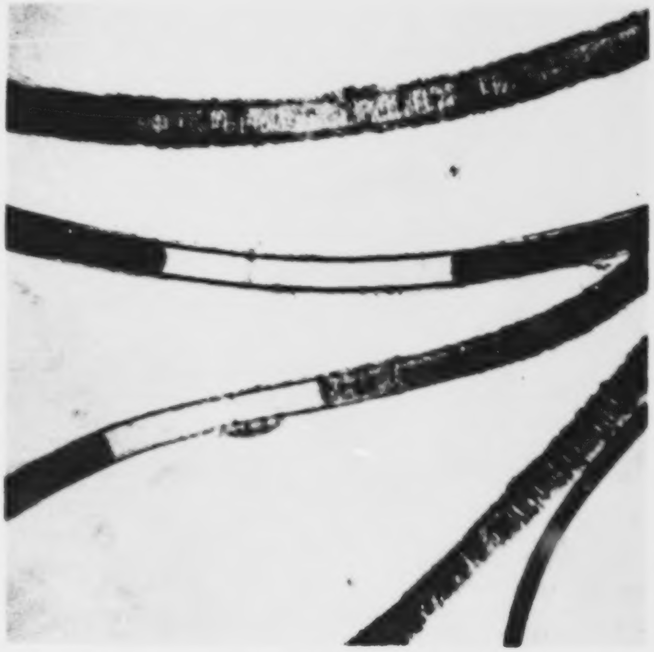

Figure 46.—*Lyngbya majuscula*, showing empty sheath extending between threads of cells.

Finland, Australia, and South Africa (28). The outbreaks have occurred only during the summer months when algae are abundant. The symptoms associated with poisoning by the blue-green algae are generally prostration and convulsions followed by death.

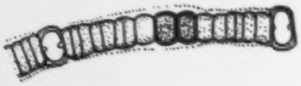

Figure 47.—*Nodularia spumigena*, the first blue-green alga reported as toxic.

A few aquatic algae are known to infect the gills of fish, causing a disease which interferes with respiration and is often fatal (29). The dinoflagellate *Oodinium ocellatum* parasitizes small fresh-water fishes. Other species of this genus occur in the marine tunicates, annelid worms, and other aquatic invertebrates (30).

Fish kills in fresh-water lakes and reservoirs have often been blamed, with considerable justification, on the algae. When there is a heavy algal growth, a reduction in the amount of sunlight due to weather conditions will reduce the photosynthetic activity of the algae. With insufficient byproduct oxygen being produced the algae are forced to use in respiration the oxygen stored in the water. If this condition should exist for any length of time, the water would lose most of its oxygen causing the algae and in addition the fish to die of oxygen starvation.

On the other hand, normal amounts of sunshine on a very thick mat of algae can bring about a fish kill. If the mat becomes thick enough to prevent the passage of light to planktonic algae below the surface, the latter will then use up more oxygen than is produced and oxygen depletion takes place which, in turn affects the fish.

A balance tends to exist between the amount of algae, the sunlight, and the total oxygen requirements of the fish and other aquatic organisms. A rise in water temperature might easily be the factor which stimulates an excessive growth of algae and thereby sets off the chain of events leading up to oxygen starvation and a fish kill (31).

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CHAPTER XI

ADDITIONAL USES FOR ALGAE FOUND IN WATER SUPPLIES

REFERENCE has already been made (ch. VI) to the utilization of algae as indicators of domestic sewage pollution and of natural purification in streams. They are also considered useful as indicators of the sources of a particular water supply, the pollution of ground water supplies with surface water, the progress of sewage change in oxidation ponds, the pollution of marine and estuarine waters, the pH and temperature ranges of a stream or lake, the toxicity of industrial wastes, and the relative abundance in water of chemicals such as sodium chloride, iron, and calcium phosphate.

INDUSTRIAL USES

Algae also constitute the raw materials used commercially in the manufacture of sodium alginate, agar, iodine, diatomaceous earth, and various food products. The food products known under various names such as amanori, kombu, kan-ten, carrageen, dulse, and limu are an important part of the diet in Hawaii, Japan, China, the Philippines, Ireland, and several other areas. These products are derived principally from marine algae.

The utilization of fresh-water algae in large amounts awaits the development of practical methods for their mass culture and harvesting (1). Their potential value as producers of concentrated protein, carbohydrate, and fat is very great, for there is no waste in the form of fibrous or woody portions that are always present in land plants. The cheapest source of nutrients for their mass culturing is undoubtedly sewage and organic industrial wastes. Investigations are now under way to develop practicable methods for the utilization of sewage in the production of algae that would be suitable for animal feeds, fertilizers, and other products (2). Algae may serve in the near future as commercial sources for vitamins, hormones, and antibiotics (3). It has been estimated that, each year, about 5 million tons of algal nutrients are wasted in the United States alone by present methods of sewage disposal (4). Where algae are grown in a closed system for treatment of sewage, there need be no waste of the nutrients.

ALGAE AS WATER SOURCE INDICATORS

It is often possible to determine the probable source of a sample of surface water through a determination of the number and kinds of algae and related organisms present. This is possible because the number and kinds of microorganisms which develop are related to the hydrographic features of bodies of water. Six chief types of lakes, for instance, are: (a) the hard water lake with an outlet; (b) hard water landlocked lake; (c) soft water lake with an outlet; (d) soft water landlocked lake; (e) acid bog lake; and (f) alkaline bog lake.

The hard water lake with an outlet tends to have an algal flora that is predominantly the blue-green-diatom type. Typical components of this hard water landlocked lake include an equal abundance of greens and blue-greens plus some of the euglenoids and yellow-greens (Chrysophyta). In the soft water lake with an outlet, the algal flora is predominantly composed of green algae and the total number is low. The soft water landlocked lake has a scant algal flora and the filamentous forms are practically nonexistent. This type of lake may tend to produce blooms of blue-green algae, but the number of species involved would still be small. In an acid bog lake, a great variety of desmids will be present. Certain particular species of blue-greens can be expected. Plankton forms are not abundant but filamentous ones will be well developed and common. The alkaline bog lake has an algal flora which is poor both in numbers and kinds. Hard water organisms such as *Chara* and *Spirogyra crassa* and *Spirogyra decimena* are often abundant (6). A knowledge of the typical algal floras of various lakes which represent the sources of a water supply will help, therefore, in determining the breeding grounds of the particular algae that interfere with the treatment or use of the water.

ALGAE IN WASTE TREATMENT SYSTEMS

Reference has been made in chapter VI to the use of algae for production of oxygen in sewage stabilization ponds. Research carried out in California (7) has indicated that the determination of the number and kinds of the more abundant algae in these ponds can be used as a reliable index of the progress in oxidation of the sewage. If the effluent contains principally *Chlorella*, the pond is assumed to be working at or over its capacity. If it contains a mixed flora the pond can handle a heavier load. *Chlamydomonas* is one of the common forms in the mixed flora which develops when most of the organic matter is gone and mineral nutrients have been precipitated because of a high pH. *Chlamydomonas*, in turn, appears to excrete an organic compound which again makes the minerals available for algal growth.

Examination of the pond effluent for its algal flora may, therefore, be a useful tool for operators of sewage plants having sewage stabilization ponds. The microscopic examination would require only a few minutes, and no extensive training is required to recognize the few types of algae important here. It has not yet been determined whether the procedure is applicable for use in all parts of the country.

Algae may also be put to use in the treatment of industrial wastes. By selection and adaptation of particular strains of algae as well as of molds, yeasts, and bacteria, it may be possible to bring about, biologically, changes in industrial wastes which otherwise might be toxic or in other ways unsuitable for release into streams, lakes, or marine waters. The use of algae would be particularly advantageous when release of oxygen into the waste is one of the required factors (5). The process has already been developed for treatment of oil wastes from refineries.

ALGAE AS MARINE POLLUTION INDICATORS

Pollution of estuaries and of coastal marine waters is rapidly becoming a problem at bathing beaches and where the ocean frontage is used for residences, for industry, and for recreation. Pollution is also influencing the marine fishing and shellfish industries.

As with fresh-water forms, severe pollution in salt water first tends to reduce the marine algal population to a few of the more resistant species, but the decomposition products, in turn, stimulate a vigorous subsequent growth of algae. In marine polluted areas in northern Europe, the sewage pollution is reported to prevent the growth of the brown rock weed, *Fucus*, while algae that are stimulated include *Blindingia minima*, *Enteromorpha*, *Ulva lactuca*, *Porphyra leucosticta*, *Erythrotrichia carnea*, *Acrochaetium virgatulum*, *Acrochaetium thuretii*, and *Calothrix confervicola*. In addition to these large sea-weed algae, microscopic planktonic algae thrive in the polluted areas, causing a decrease in the transparency of the water (8). The sea lettuce, *Ulva latissima*, is stimulated to active growth by sewage in England (9). Industrial pollution in an estuary, involving principally iron sulfate, stimulated the growth of the pollution alga *Chlorella variegata* and caused the sensitive diatoms *Chaetoceros* and *Skeletonema* to settle out (10).

Marine and brackish water diatoms are being studied to determine their usefulness as indicators of pollution with either domestic sewage or industrial wastes. One apparatus for obtaining the diatoms from the water is a slide rack with floats known as a diatometer (11). Its use is being studied in both fresh and salt waters.

TEMPERATURE, pH AND TOXICITY

Several physical characteristics of water are influenced by utilization of the water for industrial purposes. The largest single industrial use is cooling, and the prospects are that this use will increase very rapidly. In general, the various classes as well as individual species of algae have minimum, optimum, and maximum temperatures for growth. The optimum temperature for diatoms is 18°–30° C., for green algae, 30°–35° C., and for blue-green algae, 35°–40° C., according to Cairns (12). He reports that the diatom *Gomphonema parvulum* grew best at 22° C., and still showed considerable growth at 34° C., while another diatom *Nitzschia linearis* which grew best at 22° C. showed little or no growth at 30° C. Temperature changes are considered more important than any other environmental factor in influencing diatom growth (13). A few blue-green algae are capable of growth at temperatures much higher than 40° C. The optimum temperature for *Oscillatoria filiformis* is 85.2° C. The types of algae found in a particular stream may be a good indication of the range in temperature that the water has experienced.

Change in pH of water due to industrial wastes or to natural causes will also greatly modify the algal population. Mine wastes tend drastically to lower the pH and reduce the algal flora to a few acid-tolerant forms such as *Euglena mutabilis*, *Ochromonas*, *Chromulina ovalis*, *Lepocinclis ovum*, *Cryptomonas erosa*, and *Ulothrix zonata* (14). Additional acid-tolerant algae are included in table 12.

The majority of algae grow best in water at or near the neutral point of pH, but a considerable number, particularly among the blue-green algae, develop readily or may even grow best in water with a high pH. In cultures the optimum for *Anacystis* (*Microcystis*) and for *Coccochloris* (*Gloeothece*) (fig. 48) has been found to be pH 10, with little or no growth below pH 8 (15).

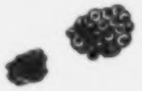

Figure 48.—*Coccochloris peniocystis.*

Other physical factors such as light and turbulence also play their part in determining the particular algal flora that will develop or remain in the water.

In bioassays to determine the toxicity of pollutants in water, certain kinds of fish and the crustacean *Daphnia* are being used. Algae also are being considered for the test. Some may become useful as indicators of toxicity, especially in waters where the wastes reduce the D.O. below that in which animals can survive. There is comparatively little information available on the tolerance limits of particular species of algae for the various toxic pollutants.

Melosira varians may be the only dominant diatom in streams polluted with oil (16). Iron, which is a pollutant from steel mills may be toxic to most algae but the flagellates *Chromulina* and *Trachelomonas hispida* (fig. 49) may remain active. Certain diatoms are also found in iron-rich water, including many species of *Eunotia* and some large forms of *Pinnularia* (16). Algae require a small amount

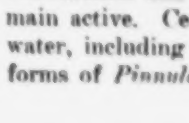

Figure 49.—*Trachelomonas hispida.*

of iron for the production of their chlorophyll and most algae grow best when the ferric oxide content of the water is between 0.2 and 2.0 mg. per liter. Distinct toxicity frequently is noted when it exceeds 5.0 mg. (17).

Copper is well known to be toxic to many algae, but some species are reported to be resistant to limited concentrations of this metal, including *Cymbella ventricosa*, *Calothrix braunii* and *Scenedesmus obliquus* (fig. 50). Others are listed in tables 12 and 13.

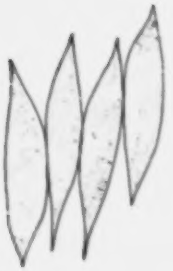

Figure 50.—*Scenedesmus obliquus.*

Phenol at a concentration of 1.9 mg. per liter appears to have no toxic effect on diatoms (18). Chromium, bromine, and many dyes from textile operations are very toxic to algae. *Spondylomorum*, *Pediastrum* (fig. 51), and *Pandorina* are capable of developing in the presence of paper mill wastes toxic to most algae (19). Distillery wastes may limit the algal growth to a few forms such as *Chlamydobotrys*, *Chlorogonium* (fig. 52), and *Chlorobrachis* (20). Hydrogen sulfide at a concentration of 3.9 mg. per liter is toxic to most diatoms. Four resistant species are *Achnanthes affinis*, *Cymbella ventricosa*, *Hantzschia amphioxys*, and *Nitzschia palea* (18). Pollution of water in oil fields and in salt works with salt brine composed largely of sodium chloride may destroy most of the normal flora. Blooms of marine or estuarine forms such as the green flagellate *Dunaliella* may develop. Many diatoms and other algae are tolerant to various concentrations of salt in water. Certain species of the following algae are reported to be remarkably resistant to the presence of chromium (21): *Stigeoclonium*, *Tetraspora*, *Closterium*, *Nitzschia*, *Navicula*, and *Euglena*.

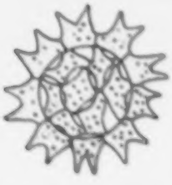

Figure 51.—*Pediastrum duplex.*

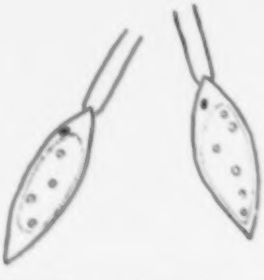

Figure 52.—*Chlorogonium euchlorum.*

Carefully controlled bioassay experiments with known wastes and cultures of algae, followed by additional observations in polluted streams, should help in obtaining more accurate information on the toxicity to algae of some of the important industrial wastes.

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Table 12.—Other Uses for Algae in Water Supplies

Problem and algae	*Algal group*
Algae as water source indicators:	
From hard water lake with an outlet:	
Blue-green algae	Blue-green
Diatoms	Diatom
Green flagellates:	
Pandorina	Flagellate
Volvox	Flagellate
From hard water lake with no outlet:	
Green algae	Green
Blue-green algae	Blue-green
Euglenoids:	
Euglena	Flagellate
Phacus	Flagellate
Trachelomonas	Flagellate
Chrysophyta:	
Synura uvella	Flagellate
Tribonema	Yellow-green
From soft water lake with an outlet:	
Desmids	Green
Diatoms	Diatom
From soft water lake with no outlet:	
Green algae	Green
From acid bog lake:	
Desmids	Green
Anacystis thermalis f. major (Chroococcus prescottii)	Blue-green
Batrachospermum	Red
Hapalosiphon pumilus	Blue-green
Microspora	Green
Oedogonium	Green
Scytonema ocellatum	Blue-green
From alkaline bog lake:	
Chara	Green
Spirogyra crassa	Green
Spirogyra decemina	Green
Algae as indicators of temperature range of waters:	
Low temperature algæ (18°–30° C.):	
Diatoms:	
Gomphonema parvulum	Diatom
Nitzschia filiformis	Diatom
Nitzschia linearis	Diatom
Medium temperature algæ (30°–35° C.):	
Green algæ	Green
Warm temperature algæ (35°–40° C.):	
Blue-green algæ	Blue-green
Hot temperature algæ (40°–85° C.):	
Coccochloris (Synechococcus)	Blue-green
Lyngbya	Blue-green
Mastigocladus laminosus	Blue-green
Oscillatoria filiformis	Blue-green
Phormidium bijahensis	Blue-green
Phormidium geysericola	Blue-green
Phormidium laminosum	Blue-green
Algae indicating progress of change in sewage oxidation ponds:	
Chlamydomonas	Flagellate
Chlorella	Green
Scenedesmus	Green
Algae as indicators of marine and estuarine pollution:	
Acrochaetium thuretii	Red
Acrochaetium virgatulum	Red
Actinastrum hantzschii	Diatom
Calothrix confervicola	Blue-green
Chlorella variegata	Green
Enteromorpha intestinalis	Green
Enteromorpha prolifera	Green
Erythrotrichia carnea	Red
Porphyra leucosticta	Red
Spirulina subsalsa	Blue-green
Ulva lactuca	Green
Ulva latissima	Green
Algae as indicators of high acidity:	
Actinella	Diatom
Chlamydomonas	Flagellate
Chromulina ovalis	Flagellate
Cryptomonas erosa	Flagellate
Euglena adhærens	Flagellate
Euglena hiemalis	Flagellate
Euglena mutabilis	Flagellate
Euglena stellata	Flagellate
Euglena tatrica	Flagellate
Euglena viridis	Flagellate
Eunotia exigua	Diatom
Eunotia lunaris	Diatom
Eunotia trinacria	Diatom
Lepocinclis ovum	Flagellate
Navicula subtilissima	Diatom
Navicula viridis	Diatom
Ochromonas	Flagellate
Penium cucurbitinum	Desmid
Pinnularia	Diatom
Stauroneis anceps	Diatom
Tabellaria flocculosa	Diatom
Ulothrix zonata	Green
Vanheurckia rhomboides var. crassenervia	Diatom
Xanthidium antilopæum	Desmid
Algae indicating industrial wastes:	
Copper:	
Achnanthes affinis	Diatom
Asterionella formosa	Diatom
Calothrix braunii	Blue-green
Chlorococcum botryoides	Green
Cymbella naviculiformis	Diatom
Cymbella ventricosa	Diatom
Navicula viridula	Diatom
Neidium bisulcatum	Diatom
Nitzschia palea	Diatom
Scenedesmus obliquus	Green
Stigeoclonium tenue	Green
Symploca erecta	Blue-green
Paper mill wastes:	
Amphora ovalis	Diatom
Caloneis amphisbaena	Diatom
Cocconeis diminuta	Diatom
Cocconeis pediculus	Diatom
Cymatopleura solea	Diatom
Cymbella ventricosa	Diatom
Diatoma vulgare	Diatom
Gomphonema herculaneum	Diatom
Navicula cryptocephala	Diatom
Navicula radiosa	Diatom
Oscillatoria	Blue-green
Pandorina	Flagellate
Pediastrum	Green
Scenedesmus	Green
Spondylomorum	Flagellate
Surirella ovata	Diatom
Surirella ovata var. salina	Diatom
Synedra pulchella	Diatom
Synedra ulna	Diatom
Ulothrix	Green
Phenolic wastes:	
Achnanthes affinis	Diatom
Ceratoneis arcus	Diatom
Cocconeis placentula	Diatom
Cyclotella kützingiana	Diatom
Cymatopleura solea	Diatom
Cymbella naviculiformis	Diatom
Diatoma vulgare	Diatom
Fragilaria virescens	Diatom
Gomphonema parvulum	Diatom
Navicula cryptocephala	Diatom
Neidium bisulcatum	Diatom
Nitzschia palea	Diatom
Pinnularia borealis	Diatom
Surirella ovata	Diatom
Synedra ulna	Diatom

Table 12.—Other Uses for Algae in Water Supplies—Continued

Problem and algae	*Algal group*
Algae indicating industrial wastes:	
Distillery wastes:	
Chlamydobotrys	Flagellate
Chlorobrachis gracillima	Flagellate
Chlorogonium euchlorum	Flagellate
Oil:	
Amphora ovalis	Diatom
Diatoma vulgare	Diatom
Gomphonema herculaneum	Diatom
Melosira varians	Diatom
Navicula radiosa	Diatom
Surirella molleriana	Diatom
Synedra acus	Diatom
Synedra ulna	Diatom
Hydrogen sulfide:	
Achnanthes affinis	Diatom
Caloneis amphisbaena	Diatom
Camphlodiscus	Diatom
Cyclotella meneghiniana	Diatom
Cymbella ventricosa	Diatom
Hantzschia amphioxys	Diatom
Navicula minima	Diatom
Neidium bisulcatum	Diatom
Nitzschia ignorata	Diatom
Nitzschia palea	Diatom
Nitzschia tryblionella var. debilis	Diatom
Surirella ovata var. salina	Diatom
Iron:	
Anomoeoneis serians var. brachysira	Diatom
Chlorella variegata	Green
Chromulina	Flagellate
Eunotia	Diatom
Gomphonema acuminatum	Diatom
Pinnularia microstauron	Diatom
Pinnularia subcapitata var. hilseana	Diatom
Stauroneis phoenicenteron	Diatom
Stenopterobia intermedia	Diatom
Surirella delicatissima	Diatom
Surirella linearis	Diatom
Trachelomonas hispida	Flagellate
Chromium:	
Closterium acerosum	Desmid
Euglena acus	Flagellate
Euglena oxyuris	Flagellate
Euglena sociabilis	Flagellate
Euglena stellata	Flagellate
Euglena viridis	Flagellate
Navicula atomus	Diatom
Navicula cuspidata	Diatom
Nitzschia linearis	Diatom
Nitzschia palea	Diatom
Stigeoclonium tenue	Green
Tetraspora	Green
Algae indicating industrial wastes:	
Salt brine (principally NaCl):	
Achnanthidium brevipes var. intermedia	Diatom
Actinastrum hantzschii	Green
Amphiprora paludosa	Diatom
Amphora coffeiformis	Diatom
Amphora ovalis	Diatom
Anacystis	Blue-green
Calothrix	Blue-green
Chaetomorpha	Green
Chlamydomonas ehrenbergii	Flagellate
Coccochloris elabens (Aphanothece halophytica)	Blue-green
Cyclotella meneghiniana	Diatom
Cymbella lacustris	Diatom
Cymbella ventricosa	Diatom
Diatoma elongatum	Diatom
Diploneis elliptica	Diatom
Dunaliella salina	Flagellate
Enteromorpha intestinalis	Green
Enteromorpha prolifera	Green
Entophysalis deusta (Aphanocapsa littoralis)	Blue-green
Euglena	Flagellate
Frustulia rhomboides var. saxonica	Diatom
Gomphonema	Diatom
Gyrosigma attenuatum	Diatom
Hantzshia elongata	Diatom
Lyngbya astuarii	Blue-green
Melosira arenaria	Diatom
Meridion circulare	Diatom
Microcoleus chthonoplastes	Blue-green
Navicula anglica	Diatom
Navicula cincta var. heufleri	Diatom
Navicula cryptocephala	Diatom
Navicula gregaria	Diatom
Navicula longirostris	Diatom
Navicula minuscula	Diatom
Navicula pygmaea	Diatom
Navicula salinarum	Diatom
Navicula subtilissima	Diatom
Nitzschia apiculata	Diatom
Nitzschia epithemoides	Diatom
Nitzschia frustulum	Diatom
Nitzschia palea	Diatom
Oscillatoria	Blue-green
Pediastrum simplex	Green
Pinnularia	Diatom
Phormidium tenue	Blue-green
Scenedesmus bijugatus	Green
Spirulina subsalsa	Blue-green
Stephanoptera gracilis	Flagellate
Synedra acus	Diatom
Synedra affinis	Diatom
Synedra pulchella	Diatom
Trachelomonas	Flagellate
Trichodesmium	Blue-green
Ulothrix	Green

CHAPTER XII

PROCEDURES FOR ENUMERATION OF ALGAE IN WATER

IT IS NECESSARY to know the purpose for which any algological investigation is to be made before a particular analytic procedure is selected. In some instances there may be need to designate only certain particular groups or genera or species of algae. This might be the case when analyzing samples from oxidation ponds to determine the progress of sewage change, or in analyzing stream samples for the presence of indicator algae or certain taste and odor algae. In other situations, a knowledge of the number as well as the general groups of algae may be required. This might be needed to determine the most effective time for treating a reservoir with an algicide. The total area or volume, particularly of the diatoms, would be useful data for determining the relationship of plankton to the length of filter runs.

For many treatment plants using surface water supplies, adequate procedures would include periodic inspections of the raw water supply, the treatment plant, and the distribution system for attached growths, and for floating mats and blooms. This would be followed by laboratory examinations, and recording of the dominant organisms present in these visible growths of algae. In addition, plankton analyses of water samples from these same areas would be made at regular intervals. Information of this sort, especially when taken over a period of time, and when supplemented by adequate physicochemical data, is very valuable for determining the type and application time of measures necessary for the prevention and control of problems brought about by algae.

No method has yet been widely accepted as accurate for reporting the number or volume of attached algae or of those in floating mats. Observations can be recorded as notes or indicated on an outline map to designate the location and the extent of the areas of algal growths. Changes in location and amount can then be followed by comparing the notes or map records for different dates. Identification of the algae can be accomplished with the aid of a microscope and a key such as included in the appendix.

In the recording of plankton algae (1) the common procedure begins with the collection of a water sample from a designated location and depth. When the sample is not to be taken immediately to the laboratory for analysis, preservation is accomplished by the addition of formaldehyde. The next step involves the concentration of the plankton in the sample by means of a centrifuge or a Sedgwick-Rafter sand filter. Using the concentrate, 1 ml. is placed in a Sedgwick-Rafter counting cell and enumeration of the organisms is made with the aid of a compound microscope fitted with a Whipple ocular micrometer. The magnification used is commonly 100X obtained by means of a 10X ocular and 10X objective. With microscopes calibrated for this type of analysis the field of view, as delimited by the ocular micrometer, can be adjusted to cover 0.001 ml. of the concentrate. The plankton organisms appearing in 10 fields are counted and, from their total, the number of organisms per milliliter, liter, or gallon of the unconcentrated water sample can be calculated (2).

Quantitative records for each genus or species may be reported separately as well as the totals for the major groups of algae. The enumeration may be in number of cells, number of clumps (isolated cells plus colonies), areal standard units, or cubic standard units. Several variations of the clump count method are in use. No single method of enumeration has been selected as a standard procedure to be followed by water treatment laboratories. However, the clump count procedure is probably the simplest method and also the basic one, since the others are often derived from it by extrapolation.

The low magnification of 100X commonly used in counting plankton, together with the loss of significant numbers of algae during preservation and concentration of the samples results in plankton values lower than those actually present. It has been estimated that many waters contain a larger volume of minute nannoplankton than of the larger forms readily visible under low magnification. In one experiment the use of a nannoplankton counting slide (fig. 53) gave an average clump count of 3,055 algae per ml., while

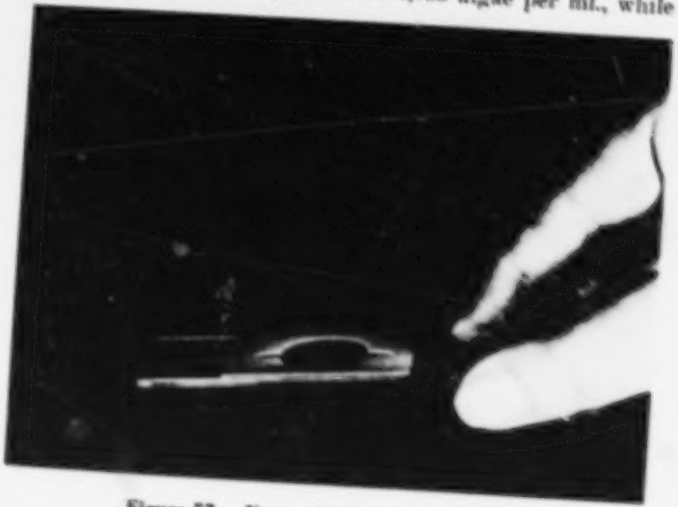


Figure 53.—Nannoplankton counting slide.

the count with the Sedgwick-Rafter slide was only 1,165 (3). When samples from four different water sources were used, the count with the nannoplankton slide in each case was significantly higher than with the Sedgwick-Rafter slide because many small algae were missed by the lower magnification used in the latter method.

A number of the pigmented flagellates and diatoms are so small that the very high magnification of an oil immersion objective lens is required for their identification and enumeration. Even the nannoplankton slide cannot be used with the oil immersion lens because of the very short focal length of that lens. However, if a drop of known volume of the concentrate is placed on a standard microscope slide and covered with a No. 1 cover glass so that the drop spreads out to occupy the area beneath it, the organisms can be counted for a known portion of this area, and an extrapolation may then be made to indicate the number per ml. (4).

Special care may have to be taken to obtain accurate records of some of the algal flagellates that are taste and odor producers or that may be indicators of clean water. When preserved in formalin they may be changed to such an extent that they are difficult to identify (4). They become distorted in form, or altered in color, and the flagella are lost. This is true particularly of *Cryptomonas*, *Chroomonas*, *Rhodomonas*, *Chromulina*, *Synura*, *Uroglenopsis*, *Eudorina*, *Mallomonas*, and *Merotrichia*. Even *Euglena* may be so distorted as to prevent its identification to species. Unpreserved samples may be required, therefore, when accurate records of these sensitive algae are needed.

Where there is special interest in enumerating all kinds and sizes in a water supply, the usual procedures for plankton enumeration may have to be modified. For the larger forms (mesoplankton), a 100-liter water sample is passed through a silk bolting cloth net, size 25, which has 200 meshes to the linear inch and apertures of 30–40 microns width. The organisms caught by the net are then washed into 5 percent formalin with a final volume of 100 ml. This would give a concentration of 1,000 to 1, which might be too high and need dilution for easier counting. Enumeration may be accomplished with a 1-ml. sample in a Sedgwick-Rafter slide using a magnification of 25X. The count should be limited to organisms 30 microns or more in width or diameter, which would involve principally the ciliates, crustacea, and other animal forms rather than algae. Extrapolation will depend on the actual sample concentration used.

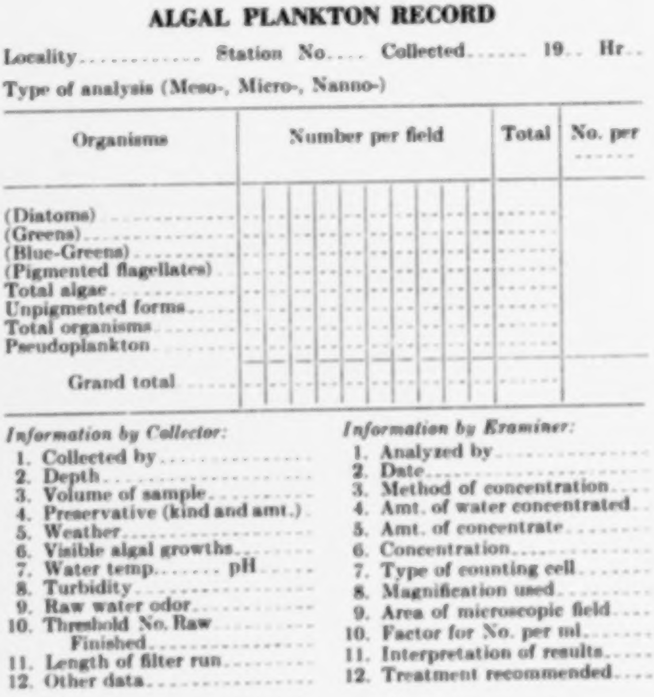
The smaller forms of plankton can be obtained in numbers sufficient for counting by using the Foerst centrifuge for concentrating the sample. At a speed in excess of 15,000 r.p.m., the 525 ml. is centrifuged at a flow such as to permit its completion in 3 minutes. The concentrate can then be washed into a bottle and the volume brought up to 20 ml. This gives a concentration of 25–1 which may have to be reduced for some samples if the algae are found to be too numerous per field under the microscope.

Enumeration of the organisms in the concentrate would be made first using the common procedure, with a Sedgwick-Rafter slide under a magnification of 100X. A concentration providing from 10 to 100 organisms per microscopic field tends to reduce the counting error, providing the range in width or diameter of the organisms is 5 to 30 microns (microplankton). The forms from 1 to 5 microns (nannoplankton) may be enumerated with much greater precision by using a counting slide which permits the use of a magnification of 430X. Some specialized work may require a magnification of approximately 1000X.

The combined results of the three procedures can then be summarized as follows:

Net (meso-) plankton	No. per 100 ml
Microplankton	No. per ml
Nannoplankton	No. per ml

A typical form for use in recording the results of the analysis for plankton algae is shown in figure 54:



ALGAL PLANKTON RECORD

Locality............ Station No.... Collected...... 19.. Hr..

Type of analysis (Meso-, Micro-, Nanno-)

Organisms	Number per field										Total	No. per ......
(Diatoms)...........												
(Greens)...........												
(Blue-Greens)...........												
(Pigmented flagellates)..												
Total algae...........												
Unpigmented forms........												
Total organisms........												
Pseudoplankton........												
Grand total......												

Information by Collector:

1. Collected by...............
2. Depth...............
3. Volume of sample..........
4. Preservative (kind and amt.).
5. Weather...............
6. Visible algal growths........
7. Water temp........ pH.....
8. Turbidity...............
9. Raw water odor..........
10. Threshold No. Raw..........
    Finished...............
11. Length of filter run..........
12. Other data...............

Information by Examiner:

1. Analyzed by...............
2. Date...............
3. Method of concentration....
4. Amt. of water concentrated..
5. Amt. of concentrate........
6. Concentration...............
7. Type of counting cell........
8. Magnification used........
9. Area of microscopic field....
10. Factor for No. per ml.......
11. Interpretation of results.....
12. Treatment recommended....

Figure 54.—Typical form of algal plankton record.

The interpretation of plankton records has seldom been based on a predetermined set of criteria. There are, however, a number of aids for interpretation which at least have a limited or localized use.

For example, a water source for which the environmental factors are not too variable from year to year would tend to produce similar amounts of algal growth each year. Experience indicates that this constitutes a useful working basis. Pearsall et al. (5) make the following statement: "We should expect, on this basis, that each year we might get algal growth that would tend to consist of a similar number of cell divisions in succession, to show a similar rate of growth and to yield a similar maximum number. It is clear that the possibility of forecasting depends largely upon this being approximately correct, as it appears to be." Thus, the plankton records of previous years may give good clues as to particular times during each season when large numbers or particular types of interference organisms are likely to appear.

Pearsall, et al. emphasize, in addition, the form and structure of particular plankters as indicative of whether their numbers will increase or decrease. They state "that populations of algae that are not growing or that are approaching their numerical maximum tend to show certain changes in appearance. When these changes can easily be recognized, they afford useful indications of the end of a period of algal growth. This is often extremely useful when the question arises of whether or not to apply treatment."

In some areas the plankton count of the raw water has been correlated with the threshold odor test, and in one state the plankton count of the raw water has been suggested as a means of predicting the probable plankton count of the finished water following coagulation and rapid sand filtration. (6).

The number of organisms and the number of areal standard units of organisms have been used to determine the amount of trouble to be expected and the time when treatment should begin. Thus, Whipple (7) stated that "when organisms were less than 500 per cc. they would cause no trouble; between 500 to 1,000 per cc., little trouble; between 1,000 and 2,000, noticeable trouble; between 2,000 and 3,000, decided trouble; and above 3,000, trouble would be serious."

At one treatment plant, where lake water was being used, the length of the filter run was found to be reduced rapidly with an increase in areal standard units of algae from 50 to about 300. When the areal standard units of algae were 50 the probable filter run was 70 hours; with 100 areal units, the filter run dropped to 35 hours; with 200 units, 18 hours; with 400 units, 11 hours; and with 1,000 units, 6 hours.

Recently a diatometer has been described for sampling the diatom population of a stream (8). By enumerating and identifying up to 8,000 or more diatom specimens obtained from the diatometer, it is possible, through statistical analysis, to determine the frequency distribution and to construct a truncated normal curve for the sample. The height and position of the mode, shape of the curve, number of frequency intervals, number of observed species, number of species in the theoretical universe, and number of specimens required for construction of the curve are reported to be important in evaluating the data for indications of water pollution. Thus, when the water is relatively free of pollution, the number of species in the mode is high (generally between 20 and 28), the mode is located between the second and fourth intervals, the curve covers only 10 or 11 intervals, the number of observed species is generally between 120 and 180, the theoretical universe contains from 150 to 210 species, and the number of specimens required for the count is low (approximately 8,000).

In stream areas adversely affected by pollution the number of species in the mode, number of observed species, and number in the theoretical universe will all be reduced in varying amounts corresponding to the degree of pollution.

In stream areas slightly enriched by nontoxic organic materials, the height of the mode remains about the same as that for the clean water station but the curve extends to the right as a "tail." With increased pollution or with toxic materials also present, the height of the mode will decrease, the "tail" will usually extend still farther, the curve may cover as many as 14 to 16 intervals, and up to 40,000 specimens must be counted before the mode is evident. It is due to the fact that diatoms can be obtained in large numbers in surface waters that this type of statistical analysis can be made.

In summary, it is evident that among the many procedures for enumeration of algae it is necessary to select those that will produce the amount and kind of information needed for satisfactory treatment and use of each particular water supply.

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CHAPTER XIII

CONTROL OF ALGAE

IT IS BETTER to anticipate and prevent problems from algae than to delay until they become serious. Effective control of algal growth requires adequate records as to the numbers, kinds, and locations of algae in the water supply.

Control of algae applies variously to the raw water supply, to the treatment plant, and to the distribution system. The use of algicides will be considered in more detail under raw water applications, although similar procedures may sometimes be applied in the other two control areas.

CONTROL IN RAW WATER SUPPLIES

The application of an algicide frequently is carried out to prevent or destroy the excessive growths of algae which occur as blooms, mats, or as high concentrations of plankton. However, the algicide may sometimes be applied to control relatively low concentrations of certain algae, such as *Synura* and *Uroglenopsis*, which may cause trouble even in small numbers.

Copper sulfate is the only algicide in common use in water supplies at present, although chlorine may serve as an algicide besides as a bactericide or an oxidizing agent. The "blue stone" or copper sulfate is toxic to many algae at comparatively low concentrations, is ordinarily nonlethal to fish at the strengths recommended, and is relatively inexpensive. However, in alkaline waters, it precipitates quickly as copper carbonate and more slowly as copper hydrate, and in such instances is considered to be effective as an algicide only for a short time following its application. Bartsch (1) emphasizes that the dosage should be dependent upon the alkalinity of the water and states that the following rule has been used successfully in various midwestern lakes: If the methyl orange alkalinity is less than 50 p.p.m., the blue stone ($CuSO_4 \cdot 5H_2O$) is effective at the rate of 0.9 pound per acre-foot. If the methyl orange alkalinity is greater than 50 p.p.m., the rate should be 5.4 pounds per acre. In the waters with a high alkalinity the dosage is not dependent upon depth since precipitation would make it ineffective below the surface.

The various genera and species of algae are not all alike in their reaction to copper sulfate and this factor has frequently been neglected in determining the concentration of the algicide to be applied. A number of the very minute planktonic green algae are very resistant to the toxic effects of blue stone. The stoneworts, *Chara* and *Nitella*, are also considered to be resistant as are a few of the green flagellates and some of the filamentous blue-green algae. The diatoms as a group are relatively susceptible but they have often developed in large numbers following the destruction of other algae through treatment with copper sulfate.

Fortunately a considerable number of the taste and odor and filter clogging algae are very susceptible even to low concentrations of the algicide. All of the following interference algae are normally considered as being very susceptible to copper sulfate: *Asterionella*, *Fragilaria*, *Tabellaria*, *Spirogyra*, *Ceratium*, *Dinobryon*, *Synura*, *Anabaena*, and *Anacystis* (*Microcystis*). A more complete list of the genera of algae, grouped according to their reported susceptibility to the toxic effect of copper sulfate is given table 13.

The lowest concentration of copper sulfate which is toxic for a particular alga also varies according to the abundance of the alga, the temperature of the water, the alkalinity of the water, the amount of organic material in the water, and other factors. Thus, the listing of a specific concentration of an algicide as the minimum effective dosage is not reliable unless these other factors have first been taken into consideration. In table 13, therefore, the grouping of the algae is by very general ranges in the dosage required for treatment. The information used in preparing table 13 was obtained from several sources, including Hale (2), Cox (3), Prescott (4), Maloney and Palmer (5), Pearsall et al. (6), and Matheson (7).

There are a number of chemical groups which contain compounds that are algicidal. The most promising of these groups include the inorganic salts, organic salts, rosin amines, antibiotics, quinones, substituted hydrocarbons, quaternary ammonium compounds, amide derivatives, and phenols (8). The chemicals, to be selected as satisfactory for use in domestic water supplies, will have to be not only economically feasible but also nontoxic to animal life and to plants other than algae. As these will probably cost more per pound than the algicides now in use, they will, therefore, be used only where careful plankton records are kept, which would permit early localized treatment to prevent undesirable species of algae from increasing in number. Algicides which are selectively toxic to the algae which produce tastes and odors, mats or blankets (fig. 55), blooms, slimes, and other undesirable conditions, and clog filters would be particularly valuable.

A pretreatment basin may simplify the control of algae and algal odors when the raw water has a high algal productivity. The algicide is released continuously into the water as it enters the basin. Cement baffles installed in the basin and arranged alternately from the two sides forces the water to flow zig-zag through the basin before reaching the outlets. For one supply in Wisconsin where this procedure has been in use, the algal population is consistently and radically reduced. The threshold odor number also has been reduced an average of 67 percent (9).

Continuous treatment with copper sulfate of Croton Lake Reservoir in New York was established about 1925. The copper sulfate dosage over a period of almost 20 years averaged 0.18 parts per million (p.p.m.) and the overall reduction of plankton for this period was 65 percent (10).

A number of methods other than by algicides are in use for the control of algae in raw water supplies. An increase in turbidity due to silt will tend to reduce the phytoplankton population by limiting the penetration of light that is essential for the growth of algae. Thus, in shallow reservoirs, fish which stir up the bottom mud and make the water turbid will aid in controlling plankton populations. A turbidity of 100 p.p.m. in rivers may be sufficient to cause plankton algae to disappear but they quickly reappear as the turbidity decreases (11).

Attached algae and water weeds can become a problem in the shallow margins of lakes and reservoirs. When sodium arsenite can not be employed, these forms are often difficult to control (12). The common procedure is to cut them or pull them out. One Connecticut utility riprapped the shore of the reservoir in an attempt to eliminate their growth.

Mechanical removal of algae may be the simplest way of disposing of massive growths which become detached and washed ashore or which collect in localized areas of the reservoir. This is of particular importance where the reservoir or lake is used for recreational purposes as well as for domestic water supply. Reduction in the amount of plankton algae in a lake has been attempted by passage of the water through a rapid sand filter, the filtered water being returned to the lake (13). The backwash containing the algae collected by the filter can be used as a land fertilizer or disposed of in a lagoon.

For new reservoirs, clearing the site of vegetation and organic debris before filling will reduce the nutrients that otherwise would be present to stimulate algal growths. For all water supply reservoirs, provisions should be put into effect as early as possible for keeping the inflow of nutrients to a minimum. These would include measures for reducing the runoff from agricultural land and the selection of a supply as free as possible of upstream sewage effluents and other organic wastes. The degree of sewage treatment generally has little or no effect in reducing the potential nutrient value of the sewage for algae. Chemical methods of extracting nitrates, phosphates, and other nutrients from water are not as yet considered to be economically practical.

When a reservoir receives its water from a stream there is a period of time after which the stream plankton dies out in the reservoir and before the reservoir plankton has had time to develop. The ideal period of storage, as far as water with a low plankton count is concerned, therefore, may be between 10 and 14 days (14) rather than a longer period of 28 to 30 days that has often been recommended in the past. It is not often possible, of course, for the capacity of the reservoir to be governed by this consideration.

The particular position and depth of the raw water supply intake in a reservoir or lake often predetermines the quality of the water which will enter the treatment plant. In order to ascertain the optimum position and depth for the intake a knowledge of the biological as well as the chemical and physical characteristics of the water at various locations is required. For one water supply in Europe, 3 years of investigations of plankton and water temperature indicated that a depth of 60 meters was to be recommended for the intake. This depth was below the area of greatest density of plankton, and below the autumn thermocline and the strata of greatest decomposition and mineralization of organic matter. No important improvement in quality of water would have been obtained by placing the intake at a greater depth (15).

Table 13.—Relative Toxicity of Copper Sulfate to Algae

Group	Very susceptible	Susceptible	Resistant	Very resistant
Blue-green	Anabaena, Anacystis, Aphanizomenon, Gomphosphaeria, Rivularia.	Cylindrospermum, Oscillatoria, Plectonema.	Nostoc, Phormidium	Calothrix, Symploca.
Green algae	Closterium, Hydrodictyon, Spirogyra, Ulothrix.	Botryococcus, Cladophora, Coelastrum, Draparnaldia, Enteromorpha, Gloeocystis, Microspora, Tribonema, Zygnema.	Characium, Chlorella, Chlorococcum, Coccomyxa, Crucigenia, Desmidium, Golenkinia, Mesotaenium, Oocystis, Palmella, Pediastrum, Pithophora, Staurastrum, Stigeoclonium, Tetraedron.	Ankistrodesmus, Chara, Elaktothrix, Kirchneriella, Nitella, Scenedesmus.
Diatoms	Asterionella, Fragilaria, Melosira, Navicula.	Gomphonema, Nitzschia, Stephanodiscus, Synedra, Tabellaria.	Achnanthes, Cymbella, Neidium.	
Flagellates	Dinobryon, Synura, Uroglenopsis, Volvox.	Ceratium, Cryptomonas, Euglena, Glenodinium, Mallomonas.	Chlamydomonas, Peridinium, Haematococcus.	Eudorina, Pandorina.

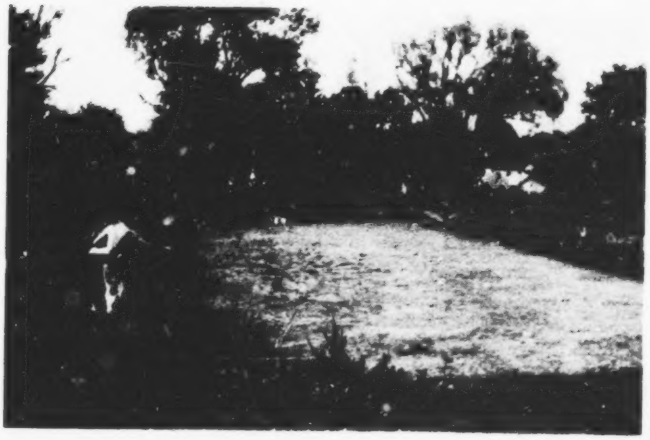

Figure 55a.—Experimental testing of a potential algicide: Applying the algicide to a blanket of algae.

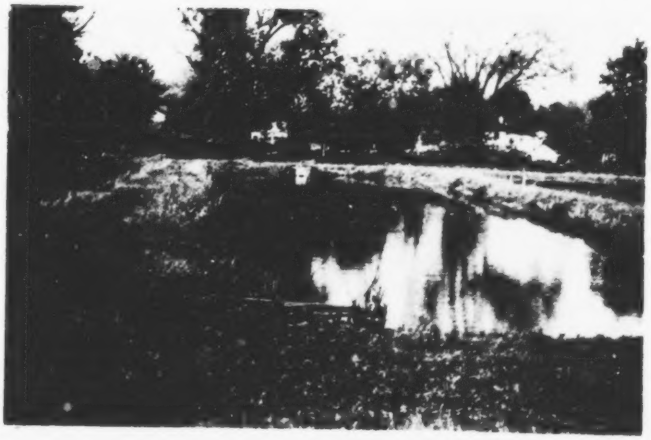

Figure 55b.—Experimental testing of a potential algicide: Result of the test: Blanket of algae has disappeared.

CONTROL IN TREATMENT PLANTS

Control of algae in the water treatment plant involves primarily the processes of coagulation, sedimentation, and filtration. Well regulated coagulation with sedimentation will often remove up to 90 percent of the algae, and in some cases 95–96 percent removal has been reported. A similar percentage of removal may occur in a rapid sand filter run efficiently. Assuming 90 percent removal by each of the two processes, 1,000 algae per ml. in raw water would be reduced to 100 by coagulation and to 10 by filtration. However, if the removal was only 70 percent in each case, the treated water would still contain 90 algae per ml. The percentage removal by coagulation tends to be low when the number of algae in the raw water is low but the efficiency of the process can be improved through the use of a coagulant aid such as activated silica.

Treatment with chlorine is often carried out in the plant primarily to destroy pathogenic organisms, but the dosages commonly used are sufficiently high to be toxic also to many algae. However, dead as well as living organisms can cause tastes and odors and clog filters. Coagulation of motile algae such as *Euglena* may be improved by prechlorination. When plain sedimentation is used, prechlorination will kill many of the algae and facilitate their settling out, since their motility is stopped and their buoyancy due to oxygen production in photosynthesis is reduced.

A process known as micro-straining is being used in some treatment plants particularly in England. This involves the passing of the water through a finely woven fabric of stainless steel. The size of the openings in the mesh determines the size of the plankton organisms removed from the water. The micro-strainer is usually in the form of an open drum. While it revolves, that portion exposed to air is back washed with jets of water (16).

CONTROL IN DISTRIBUTION SYSTEMS

Control of algae in the distribution system is generally limited to the use of algicides in open reservoirs containing treated water. A permanent control would involve covering the reservoir to exclude light to prevent the algae from developing. Where covering is considered too costly, chlorine or copper sulfate is required at least during the warmer months. When the former is used certain chlorine-resistant algae sometimes tend to become predominant. One of these is a minute desmid belonging to the genus *Cosmarium*. Most of the algae in the distribution system either develop in the exposed reservoirs or are transient organisms remaining in the water after its passage through the treatment plant. The majority of the organisms capable of multiplying in the pipes of the distribution system are not algae but are heterotrophic forms represented by various bacteria, fungi, protozoa, worms, copepods, and other small aquatic animals.

TYPES OF CONTROL METHODS

Control of algae in water supplies thus may involve the use of algicides; the mechanical cleaning of settling basins, filters, intake channels, and reservoir margins; the modification of coagulation, filtration, chemical treatment or location of the raw water intake; and, finally, the modification of the reservoir to reduce the opportunities for massive growths. Control of tastes and odors and other algal products involves additional procedures such as the use of absorbents and the removal of organic deposits from settling basins and distribution lines. Effective control of algae is dependent upon adequate procedures for detecting their presence and interpreting the significance of any change in their numbers and kinds.

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Appendix

Key

Glossary

Bibliography

Genus and Species Index

KEY TO ALGAE OF IMPORTANCE IN WATER SUPPLIES

1a. Plant a tube, thread, strand, ribbon, or membrane; frequently visible to the unaided eye---------- 2
1b. Plants of microscopic cells which are isolated or in irregular, spherical, or microscopic clusters; cells not grouped into threads---------------- 123
2a. Plant a tube, strand, ribbon, thread, or membrane composed of cells---------------------------- 3
2b. Plant a branching tube with continuous protoplasm, not divided into cells------------------ 120
3a. Plant a tube, strand, ribbon, thread, or a mat of threads ---------------------------------- 4
3b. Plant a membrane of cells one cell thick (and two or more cells wide)-------------------------- 116
4a. Cells in isolated or clustered threads or ribbons which are only one cell thick or wide---------- 5
4b. Cells in a tube, strand, or thread all (or a part) of which is more than one cell thick or wide------ 108
5a. Heterocysts present---------------------------- 6
5b. Heterocysts absent----------------------------- 23
6a. Threads gradually narrowed to a point at one end- 7
6b. Threads same width throughout---------------- 12
7a. Threads as radii, in a gelatinous bead or mass---- 8
7b. Threads not in a gelatinous bead or mass-------- 11
8a. Spore (akinete) present, adjacent to the terminal heterocyst------------------------ (*Gloeotrichia*) 9
8b. No spore (akinete) present------------ (*Rivularia*) 10
9a. Gelatinous colony a smooth bead *Gloeotrichia echinulata*
9b. Gelatinous colony irregular-------- *Gloeotrichia natans*
10a. Cells near the narrow end as long as wide *Rivularia dura*
10b. Cells near the narrow end twice as long as wide----------------------- *Rivularia haematites*
11a. Cells adjacent to heterocyst wider than heterocyst--------------------------- *Calothrix braunii*
11b. Cells adjacent to heterocyst narrower than heterocyst----------------------- *Calothrix parietina*
12a. Branching present--------------------------- 13
12b. Branching absent---------------------------- 14
13a. Branches in pairs-------- *Scytonema tolypothricoides*
13b. Branches arising singly---------- *Tolypothrix tenuis*
14a. Heterocyst terminal only----- (*Cylindrospermum*) 15
14b. Heterocysts intercalary (within the filament)--- 16
15a. Heterocyst round-------- *Cylindrospermum muscicola*
15b. Heterocyst elongate------- *Cylindrospermum stagnale*
16a. Threads encased in a gelatinous bead or mass (*Nostoc*) 17
16b. Threads not encased in a definite gelatinous mass ------------------------------------ 18
17a. Heterocysts and vegetative cells rounded *Nostoc pruniforme*
17b. Heterocysts and vegetative cells oblong *Nostoc carneum*
18a. Heterocysts and vegetative cells shorter than the thread width--------------- *Nodularia spumigena*
18b. Heterocysts and vegetative cells not shorter than the thread width-------------------------- 19
19a. Heterocysts rounded----------------- (*Anabaena*) 20
19b. Heterocysts cylindric------ *Aphanizomenon flos-aquae*
20a. Cells elongate, depressed in the middle; heterocysts rare------------------ *Anabaena constricta*
20b. Cells rounded; heterocysts common------------ 21
21a. Heterocysts with lateral extensions *Anabaena planctonica*
21b. Heterocysts without lateral extensions---------- 22
22a. Threads 4–8 μ wide------------- *Anabaena flos-aquae*
22b. Threads 8–14 μ wide------------- *Anabaena circinalis*
23a. Branching absent---------------------------- 24
23b. Branching (including "false" branching) present 84
24a. Cell pigments distributed throughout the protoplasm------------------------------------ 25
24b. Cell pigments limited to plastids-------------- 49
25a. Threads short and formed as an even spiral---- 285
25b. Threads very long and not forming an even spiral 26
26a. Several parallel threads of cells in one common sheath------------------ *Microcoleus subtorulosus*
26b. One thread per sheath if present-------------- 27
27a. Sheath or gelatinous matrix present------------ 28
27b. No sheath nor gelatinous matrix apparent---------------------------- (*Oscillatoria*) 35
28a. Sheath distinct; no gelatinous matrix between threads ------------------------- (*Lyngbya*) 29
28b. Sheath indistinct or absent; threads interwoven with gelatinous matrix between ------------------------ (*Phormidium*) 32
29a. Cells rounded--------------------- *Lyngbya ocracea*
29b. Cells short cylindric------------------------ 30
30a. Threads in part forming spirals-- *Lyngbya lagerheimii*
30b. Threads straight or bent but not in spirals------ 31
31a. Maximum cell length 3.5 μ; sheath thin----------------------------- *Lyngbya digueti*
31b. Maximum cell length 6.5 μ; sheath thick *Lyngbya versicolor*
32a. Ends of some threads with a rounded swollen "cap" cell-------------------------------- 33
32b. Ends of all threads without a "cap" cell-------- 34
33a. End of thread (with "cap") abruptly bent--------------------- *Phormidium uncinatum*

33b. End of thread (with "cap") straight *Phormidium autumnale*

34a. Threads 3–5 μ in width ------ *Phormidium inundatum*

34b. Threads 5–12 μ in with ---------- *Phormidium retzii*

35a. Cells very short, generally less than one-third the thread diameter ---------------------------- 36

35b. Cells generally one-half as long to longer than the thread diameter ------------------------ 39

36a. Cross walls constricted ----------- *Oscillatoria ornata*

36b. Cross walls not constricted -------------------- 37

37a. Ends of thread, if mature, curved ----------- 38

37b. Ends of thread straight ---------- *Oscillatoria limosa*

38a. Threads 10–14 μ thick --------- *Oscillatoria curviceps*

38b. Threads 16–60 μ thick --------- *Oscillatoria princeps*

39a. Threads appearing red to purplish -------------------- *Oscillatoria rubescens*

39b. Threads yellow-green to blue-green ------------ 40

40a. Threads yellow-green ------------------------ 41

40b. Threads blue-green -------------------------- 43

41a. Cells 4–7 times as long as the thread diameter ------------------------ *Oscillatoria putrida*

41b. Cells less than four times as long as the thread diameter ---------------------------------- 42

42a. Prominent granules ("pseudovacuoles") in center of each cell ------------ *Oscillatoria lauterbornii*

42b. No prominent granules in center of cells ------------------------ *Oscillatoria chlorina*

43a. Cells ½–2 times as long as the thread diameter -- 44

43b. Cells 2–3 times as long as the thread diameter -- 48

44a. Cell walls between cells thick and transparent ------------------ *Oscillatoria pseudogeminata*

44b. Cell walls thin, appearing as a dark line -------- 45

45a. Ends of thread straight -------- *Oscillatoria agardhii*

45b. Ends of mature threads curved --------------- 46

46a. Prominent granules present especially at both ends of each cell --------------- *Oscillatoria tenuis*

46b. Cells without prominent granules -------------- 47

47a. Cross walls constricted --------- *Oscillatoria chalybea*

47b. Cross walls not constricted ------ *Oscillatoria formosa*

48a. End of thread long tapering --- *Oscillatoria splendida*

48b. End of thread not tapering ---- *Oscillatoria amphibia*

49a. Cells separate from one another and enclosed in a tube ------------------------- (*Cymbella*) 251b

49b. Cells attached to one another as a thread or ribbon -- 50

50a. Cells separating readily into discs or short cylinders, their circular face showing radial markings ------------------------------ 233a

50b. Cells either not separating readily, or if so, no circular end wall with radial markings ------ 51

51a. Cells in a ribbon, attached side by side or by their corners ------------------------------ 52

51b. Cells in a thread, attached end to end --------- 56

52a. Numerous regularly spaced markings in the cell wall -------------------------------------- 53

52b. Numerous markings in the cell wall absent ------------------------- (*Scenedesmus*) 128

53a. Wall markings of two types, one coarse, one fine ---------------------------------- 185

53b. Wall markings all fine -------------- (*Fragilaria*) 54

54a. Cells attached at middle portion only ---------------------- *Fragilaria crotonensis*

54b. Cells attached along entire length ------------ 55

55a. Cell length 25–100 μ ------------ *Fragilaria capucina*

55b. Cell length 7–25 μ ------------- *Fragilaria construens*

56a. Plastid in the form of a spiral band -- (*Spirogyra*) 57

56b. Plastid not a spiral band -------------------- 61

57a. One plastid per cell ------------------------- 58

57b. Two or more plastids per cell ---------------- 60

58a. Threads 18–26 μ wide --------- *Spirogyra communis*

58b. Threads 28–50 μ wide ---------------------- 59

59a. Threads 28–40 μ wide ------------ *Spirogyra varians*

59b. Threads 40–50 μ wide --------- *Spirogyra porticalis*

60a. Threads 30–45 μ wide; 3–4 plastids per cell ----------------------- *Spirogyra fluviatilis*

60b. Threads 50–80 μ wide; 5–8 plastids per cell *Spirogyra majuscula*

61a. Plastids two per cell ---------------------- 62

61b. Plastids either one or more than two per cell -- 66

62a. Cells with knobs or granules on the wall ------ 63

62b. Cells with a smooth outer wall ------ (*Zygnema*) 64

63a. Each cell with two central knobs on the wall *Desmidium grevillii*

63b. Each cell with a ring of granules near one end *Hyalotheca mucosa*

64a. Cells dense green, each plastid reaching to the wall ---------------------------- *Zygnema sterile*

64b. Cells light green, plastids not completely filling the cell ------------------------------- 65

65a. Width of thread 26–32 μ; maximum cell length 60 μ ------------------------- *Zygnema insigne*

65b. Width of thread 30–36 μ; maximum cell length 120 μ -------------------- *Zygnema pectinatum*

66a. Plastid a wide ribbon, passing through the cell axis -------------------------- (*Mougeotia*) 67

66b. Plastid or plastids close to the cell wall (parietal) ------------------------------- 69

67a. Threads with occasional "knee-joint" bends *Mougeotia genuflexa*

67b. Threads straight --------------------------- 68

68a. Threads 19–24 μ wide; pyrenoids 4–16 per cell *Mougeotia sphaerocarpa*

68b. Threads 20–34 μ wide; pyrenoids 4–10 per cell *Mougeotia scalaris*

69a. Occasional cells with one to several transverse wall lines near one end --------- (*Oedogonium*) 70

69b. Occasional terminal transverse wall lines not present ---------------------------- 73

70a. Thread diameter less than 24 μ ------------- 71

70b. Thread diameter 25 μ or more -------------- 72

71a. Thread diameter 9–14 μ -------- *Oedogonium suecicum*

71b. Thread diameter 14–23 μ ---------- *Oedogonium boscii*

72a. Dwarf male plants attached to normal thread, when reproducing ---- *Oedogonium idioandrosporum*

72b. No dwarf male plants produced -- *Oedogonium grande*

73a. Cells with one plastid which has a smooth surface ---------- 74

73b. Cells with several plastids or with one nodular plastid ---------- 78

74a. Cells with rounded ends ------- *Stichococcus bacillaris*

74b. Cells with flat ends ---------- (*Ulothrix*) 75

75a. Threads 10 µ or less in diameter ---------- 76

75b. Threads more than 10 µ in diameter ---------- 77

76a. Threads 5–6 µ in diameter ------- *Ulothrix variabilis*

76b. Threads 6–10 µ in diameter ------- *Ulothrix tenerrima*

77a. Threads 11–17 µ in diameter ------- *Ulothrix aequalis*

77b. Threads 20–60 µ in diameter ------- *Ulothrix zonata*

78a. Iodine test for starch positive; one nodular plastid per cell ---------- 79

78b. Iodine test for starch negative; several plastids per cell ---------- 80

79a. Thread when broken, forming "H" shape segments ---------- *Microspora amoena*

79b. Thread when fragmented, separating irregularly or between cells ------- (*Rhizoclonium*) 100a

80a. Side walls of cells straight, not bulging. A pattern of fine lines or dots present in the wall but often indistinct ---------- (*Melosira*) 81

80b. Side walls of cells slightly bulging. Pattern of wall markings not present ------- (*Tribonema*) 83

81a. Spine-like teeth at margin of end walls ------- 82

81b. No spine-like teeth present ------- *Melosira varians*

82a. Wall with fine granules, arranged obliquely *Melosira crenulata*

82b. Wall with coarse granules, arranged parallel to sides ---------- *Melosira granulata*

83a. Plastids 2–4 per cell ---------- *Tribonema minus*

83b. Plastids more than four per cell *Tribonema bombycinum*

84a. Plastids present; branching "true" ---------- 85

84b. Plastids absent; branching "false" *Plectonema tomasiniana*

85a. Branches reconnected, forming a net *Hydrodictyon reticulatum*

85b. Branches not forming a distinct net ---------- 86

86a. Each cell in a conical sheath open at the broad end ---------- (*Dinobryon*) 87

86b. No conical sheath around each cell ---------- 90

87a. Branches diverging, often almost at a right angle *Dinobryon divergens*

87b. Branches compact often almost parallel ------- 88

88a. Narrow end of sheath sharp pointed ---------- 89

88b. Narrow end of sheath blunt pointed *Dinobryon sertularia*

89a. Narrow end drawn out into a stalk *Dinobryon stipitatum*

89b. Narrow end diverging at the base -- *Dinobryon sociale*

90a. Short branches on the main thread in whorls of four or more ---------- (*Nitella*) 91

90b. Branching commonly single or in pairs ------- 92

91a. Short branches on the main thread rebranched once ---------- *Nitella flexilis*

91b. Short branches on the main thread rebranched two to four times ---------- *Nitalla gracilis*

92a. Terminal cells each with a colorless spine having an abruptly swollen base ------ (*Bulbochaete*) 93

92b. No terminal spines with abruptly swollen bases- 94

93a. Vegetative cells 20–48 µ long --- *Bulbochaete mirabilis*

93b. Vegetative cells 48–88 µ long --- *Bulbochaete insignis*

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98b. End cells abruptly pointed, mostly without long colorless tips ---------- *Chaetophora elegans*

99a. Light and dense dark cells intermingled in the thread ---------- *Pithophora oedogonia*

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GLOSSARY

Actinomycetes. A group of branching filamentous bacteria, reproducing by terminal spores. They are common in the soil. Selected strains are used for production of certain antibiotics.

Aeration. The mixing of water or other liquid with air, including the absorption of air through the surface of the liquid.

Aerobic. A condition involving the presence of free (elementary) oxygen in a medium such as water or sewage.

Algae (singular, alga). Comparatively simple plants containing photosynthetic pigments. A majority are aquatic and many are microscopic in size.

Algicide (or algaecide). A chemical highly toxic to algae and satisfactory for application to water.

Alpha-mesosaprobic zone. Area of active decomposition, partly aerobic, partly anaerobic, in a stream heavily polluted with organic wastes.

Alternate branching. Only one branch per node or at any one height on a filament or strand.

Anaerobic. A condition involving the absence of free (elementary) oxygen in a medium such as water or sewage.

Anterior. The front or forward end of an organism that is capable of movement.

Aquatic. Living in water.

Arcuate. Moderately curved, like a bow.

Areal standard unit. An area of 400 square microns, used as a unit in designating the amount of plankton in water.

Armored flagellates. Flagellates having a cell wall composed of distinct, tightly arranged segments or plates. The wall is generally thick, rough and brown.

Aromatic. A fragrant, spicy or pungent odor.

Attenuation. A continuous decrease in width of a filament, often to a point or thin hair.

Back wash. The cleaning of a rapid sand or mechanical filter by reversing the flow of water upward through it.

Bacteria (singular, bacterium). Simple one-celled but often colonial microorganisms, typically free of chlorophyll, and rigid in form. Their common method of reproduction is by cell division. With few exceptions they live on organic materials.

Benthic. Referring to aquatic organisms growing in close association with the substrate.

Benthos (or benthon). Aquatic microorganisms capable of growth in close association with the substrate.

Biological. Associated with or caused by living organisms.

Biology. The field of study dealing with living organisms. It may be divided into the study of plants (botany) and of animals (zoology).

Blanket algae. A mass of filamentous algae floating as a visible mat at the surface of the water.

Bloom. A concentrated growth or aggregation of plankton, sufficiently dense as to be readily visible.

Blue-green algae. The group Myxophyceae, characterized by simplicity of structure and reproduction, with cells in a slimy matrix and containing no starch, nucleus, or plastids and with a blue pigment present in addition to the green chlorophyll.

Bound carbonates. The nearly insoluble monocarbonates present in water, where a balance is maintained between the amounts of bound, half bound and unbound carbonates.

Calibration. Determination of the dimensions of a line, area or mass, present in an istrument such as a microscope. It is accomplished by measurement with a known scale.

Calyptra. A cap or lid on some terminal cells in certain filamentous blue-green algae.

Capitate. Presence of a round cell at the end of a filament; a cell with a rounded enlarged end.

Cell. The organized ultimate unit of structure and growth of a plant or animal. It is composed of a protoplast which, in plants, is generally sourrounded by a cell wall.

Cell face. The particular surface of a cell which confronts a person who is observing it under a microscope.

Cell sap. The watery fluid of a cell which may separate from the gelatinous protoplasm to form one or more vacuoles.

Cell wall. The rigid to semirigid, inert, permeable layer of cellulose, silica or other material which surrounds, and is in contact with, the protoplast of plant cells. It is to be distinguished from the flexible, selectively permeable surface membrane (ectoplast) of the protoplast, and the capsule, sheath or lorica which may be outside of the cell wall.

Centric. Refers to diatoms which are circular in form in valve view and have radial striae.

Chlorophyll. Green photosynthetic pigment, present in plant cells including the algae.

Chromatophore. A color-carrying body within a cell protoplast.

Clean water zone. That area of water, in a polluted stream, in which self-purification has been completed.

Coagulant aid. A substance which, when added with the coagulant to water, improves the formation of floc.

Coagulation. The agglomeration of suspended or colloidal matter in a liquid such as water, commonly induced by addition to the water of a floc-forming chemical.

Colloidal. A condition involving particles dispersed in a medium such as water which do not go into solution nor do they settle out.

Colony. An isolated group of cells which have developed together from a single original parent plant or reproductive cell. Each cell is theoretically capable of life activities independent of the others.

Constricted. The surface wall of a filament curved inward to meet the cross walls, thus leaving grooves on the surface of the filament.

Cooling tower. An enclosure for holding water while its temperature is decreasing. The cooling tower is part of a system which involves absorption of heat by the water from some heat generating apparatus or machinery.

Costae (single, costa). Thick, rib-like striae in diatom walls.

Cross walls. Transverse walls in a filament, dividing it into units or cells.

Crustacea. Aquatic animals with a rigid outer covering, jointed appendages and gills. Included are the water fleas such as *Daphnia* and the copepoda such as *Cyclops*.

Cubic standard unit. A volume equal to 8,000 cu. microns and used as a unit in designating the amount of plankton in water.

Culture. A growth of microorganisms in an artificial medium containing the necessary nutrients.

Desmids. Organisms belonging to the subgroup Desmidiaceae of the green algae and characterized by cells of distinctive shapes one half of which corresponds in shape, size and contents to the other half. In many desmids the two "semicells" are connected by a short narrow tube (isthmus).

Diatoms. Organisms belonging to the group Bacillariophyceae and characterized by the presence of silica in the cell walls, which are sculptured with striae and other markings, and by the presence of a brown pigment associated with the chlorophyll.

Dissolved oxygen (D.O.). The amount of elementary oxygen present in water in a dissolved state. It is commonly reported in parts per million (by weight), or milligrams per liter, of oxygen in the water.

Distribution system. Pipes or other conduits through which a water supply is distributed to consumers.

Elliptical. Narrowly oval in form, the greatest width being across the middle rather than nearer one end.

Enrichment. The addition to water of substances which increase the amounts of nutrients used by aquatic organisms in their growth.

Epitheca. The slightly larger half of the two pieces of the diatom wall. It fits as a flanged cover over the smaller but otherwise corresponding "hypotheca."

Eye piece (or ocular). The short cylindrical frame holding a lens or combination of lenses, and fitting into the top of the microscope tube.

Eye spot. A light sensitive, red to orange body within the protoplast of a flagellate.

False branching (or pseudobranching). A lateral outgrowth initiated by a cross breakage of a filament, followed by the protrusion through the sheath of one or both of the broken ends of the filament.

False raphe (or pseudoraphe). A longitudinal clear space on the valve face of a diatom, and bounded on both sides by lines of striae.

Filament. A linear series of cells, forming a thread, and held together by their cell walls or sheath.

Filter. A bed of sand or related ingredients through which water is passed to reduce the amount of solid and colloidal material in the water.

Filter clogging. The settling of algae, silt and other substances from the water into the pores and on the surface of a sand or other granular filter bed, thus reducing the rate of flow of the water through the filter.

Filter run. The time between two successive washing operations of a rapid sand filter.

Filter skin (or Schmutzdecke). The scum or gelatinous layer over the top of a slow sand filter and containing various types of aquatic microorganisms.

Filtration. The process used in water treatment plants of passing water through a granular medium such as sand for the removal or reduction in amount of suspended or colloidal matter.

Flagellum. A microscopic whip-like extension present on many of the motile algae and protozoa.

Flavor. An inclusive term for odor plus the tongue sensations of taste, texture, and temperature of a substance.

Flexible. A solid or semisolid body capable of readily changing its shape when subjected to variations in external factors.

Frustule. The cell wall of a diatom.

Fungus (plural, fungi). Simple plants without chlorophyll, and in a broad sense including both the bacteria and the molds, yeasts and mushrooms. The simpler forms are one celled; the higher forms are branching filaments.

Furrow. A groove or trench on the side of the cell of certain flagellates.

Gelatinous matrix. Semisolid material surrounding the cell wall, and for some algae, having a characteristic shape or color.

Genus. A group (in the classification system for plants and animals) into which are placed species that resemble one another more than they do other species.

Girdle view. The side, rather than the front or top view, of a diatom. It reveals the junction (girdle) of the epitheca and hypotheca.

Green algae. Organisms belonging to the class Chlorophyceae and characterized by photosynthetic pigments similar in color to those of the higher green plants. The storage food is starch.

Ground water. Water (excepting capillary water) located below the surface of the ground, generally limited to that below the water table.

Gullet. An internal sac-like cavity, open to the outside at the anterior end of the cell. It is present in certain flagellates.

Half bound carbonates. Somewhat soluble bicarbonates present in water where a balance is maintained between the amounts of bound, half bound and unbound carbonates.

Hardness. Ability of water to form a curd-like scum when soap is added and to form scale in boilers. It is caused by presence in the water of carbonates, sulfates, and other related substances.

Hay fever. Allergic symptoms involving the upper respiratory tract.

Healthy (portion of) stream. Flowing water in which the aquatic life has not been adversely affected by human activities such as pollution or by other relatively recent changes in the environment.

Heterocyst. A specialized cell in certain filamentous blue-green algae. It is larger, clearer and thicker walled than the regular vegetative cells.

Heterotrophic. Referring to organisms that for their metabolism are dependent upon organic matter supplied from sources outside of their own bodies.

Hypotheca. The smaller or bottom half of the diatom cell wall, its upturned, flanged edge fitting inside of a corresponding flange of the "epitheca."

Impoundment. A reservoir used for collection and storage of a water supply and for its controlled release as required for use.

Impurities in water. Foreign materials present in water, particularly those impairing its usefulness.

Intercalary. Located between other structures rather than at the end.

Katarobic zone. That area of a stream which is free of both organic pollution and its products.

Key. A series of paired, contrasting statements each pair leading to other pairs of statements and eventually revealing the names of organisms. It is for use in the identification of algae and other plants and animals.

Lateral. Refers to the side, in contrast to the ends, of the body of an alga or other organism.

Lorica. A rigid wall-like covering around a motile cell and separated by a space from the protoplast or cell wall. An opening is present at the anterior end, through which the flagellum extends.

Loss of head. A decrease in water pressure due to friction and commonly expressed in terms of the difference in elevations to which water will rise in open tubes.

Mat. A layer of algae, generally of the filamentous type. The layer may be either floating on the water or covering a substrate.

Membrane. A wide, flat, thin plant body. A partition or covering, such as the flexible, selectively permeable outer surface film of a protoplast.

Metabolic. Referring to the building up (anabolic) and tearing down (katabolic) processes going on within living cells.

Micron. A unit of linear measurement appropriate for describing the dimensions of microscopic organisms. It is equivalent to one one-thousandth of a millimeter.

Microorganism. Any minute organism either plant or animal, invisible or barely visible to the unaided eye.

Microscopic. An object too small to be clearly visible without the aid of a microscope.

Mold. Any fungus exclusive of the bacteria and yeasts which is of concern because of its growth on foods or other products used by man.

Mu (μ). The Greek letter μ, pronounced "mū", is used as a symbol to indicate "micron" or "microns."

Multicellular. An organism with sufficient specialization to require more than one cell for its various growth activities.

Nannoplankton. Unattached aquatic organisms which are so small that very high magnification with the microscope is required to make them clearly visible. The magnification commonly used for them is 430 to 1,200X.

Naviculoid. Having the form of a ship: pointed or wedge-shaped at both ends, and widest at the middle.

Node. A swelling, generally occurring at equal distances along the tube-like strands of certain algae.

Nonseptate. A tube-like body that is not subdivided by cross partitions.

Nucleus. An organized, specialized body within the protoplast and containing the chromatin.

Nuisance organisms. Aquatic organisms that are capable of interfering with the use or treatment of water.

Nutrient. A substance, such as a nitrate, absorbed by an organism and essential as a raw material for its growth.

Ocular (or eye piece). The lens or lens combination, fitted into a short cylindric holder which, in turn, fits into the top of the microscope tube.

Ocular micrometer. A glass disc, marked with a scale, that fits on the diaphragm of the microscope ocular.

Odor. The property of a substance, receptive to the nose, which permits pleasant or unpleasant sensations of fragrance or smells to be recognized.

Oligosaprobic zone. That area of a stream which contains the mineralized products of self-purification from organic pollution but with none of the organic pollutants remaining.

Opposite branching. With branches attached two per node or at any one height on a filament, tube or strand.

Organism. A plant or animal. A body that has developed as a result of being alive.

Outer matrix. The sheath or other cell material outside of the cell wall.

Oxidation pond. An enclosure for sewage designed to promote the intensive growth of algae. These organisms release oxygen that stimulates transformation of the wastes into inoffensive end products.

Oxygenation. The absorption by water of elemental oxygen which has been released into the water by aquatic plants as a waste product of photosynthesis.

Parietal. Located near or against the margin. A contrasting term: "axial."

Pennate diatom. A diatom which is elongate rather than circular in the valve view. The wall ornamentation is arranged along the sides of the longitudinal axis rather than about a central point.

Peripheral. Located at the margin.

Photosynthesis. Process of manufacture by algae and other plants of sugar and other carbohydrates from inorganic raw materials with the aid of light and chlorophyll.

Phytoplankton. Plant microorganisms, such as certain algae, living unattached in the water. Contrasting term: zooplankton.

Pigmented. Having color, particularly that due to the presence of photosynthetic colored material, in the cells of algae and other plants.

Pigmented flagellates. Algae that are capable of swimming and are furnished with one or more flagella. They belong to a number of classes, including Euglenophyceae, Xanthophyceae, Dinephyceae, Chlorophyceae (Volvocales only) and Cryptophyceae.

Pipe moss. A mat or mass of growth formed by aquatic organisms that are attached to the inner surface of a water pipe.

Plankton. Unattached aquatic microorganisms growing as bodies dispersed throughout the water.

Plastid. A body in a plant cell that contains photosynthetic pigments.

Pollution. Presence of foreign material in water, particularly that which interferes with its use.

Polysaprobic zone. That area of a grossly polluted stream which contains the complex organic waste matter that is decomposing primarily by anaerobic processes.

Posterior. The hinder end of the body of a swimming organism.

Potable. Referring to water which is drinkable as a result of being free of pathogens, toxic materials, tastes, odors, color and other undesirable physical, chemical and biological characteristics.

Protoplasm. The gelatinous, colloidal material of plants and animals in which all life activities occur.

Protoplast. The unit of protoplasm comprising one cell.

Protozoa. Unicellular animals, including the ciliates and nonchlorophyllous flagellates.

Pseudonodule. A clear area resembling a swelling (nodule) on a diatom wall.

Pseudoraphe (false raphe). A longitudinal clear space on the valve face of a diatom and bounded on both sides by striae.

Pseudovacuoles. Numerous minute bodies, resembling oil globules, in cells of certain planktonic blue-green algae. Their function and content are not fully determined. They appear as black granules under high magnification.

Punctae. Pores (appearing as dots) arranged in rows (striae) in diatom walls.

Pure culture. A growth in an artificial nutrient medium of a single kind of microorganism and with no other kinds of organisms present.

Pyrenoid. A body, often within a plastid, around which starch granules are aggregated.

Radii (Singular, radius). Lines extending from the center of a circle and at right angles to tangents.

Raphe. A line (cleft) or clear space extending lengthwise on the valve surface of a diatom. See true raphe and false raphe.

Rapid sand filter. A bed of sand for water treatment constructed to permit a rapid rate of flow of water through it. The rate is commonly from 2 to 3 gallons per minute per square foot of filter surface.

Raw water. Water which is available as a supply for use but which has not yet been treated or "purified."

Reaeration. Contact of air with water permitting absorption of oxygen into the water from the air.

Recovery zone. The area of a stream in which active, primarily aerobic, decomposition of the pollutants is occurring.

Red algae. A class of algae (Rhodophyceae) most members of which are marine. They contain a red pigment in addition to the chlorophyll.

Red tide. A visible red to orange coloration of an area of water caused by the presence of a bloom of certain "armored" flagellates.

Reservoir. A basin, lake, pond, tank or impoundment which is used for control, regulation and storage of water. It may be either natural in origin or created by the building of a dam or retaining wall.

Resting spore. A specialized, thick walled reproductive cell, capable of dormancy and of germination, without sexual fusion, to form a new plant.

Rhodophyceae. A class of algae popularly called "red algae." The cells contain a red pigment in addition to the chlorophyll. Mostly marine forms.

Rigid. A structure with a fixed, nonflexible form.

Rotifer. A microscopic aquatic animal with a ciliated crown attached to its head. The cilia give the appearance of moving in a regular procession around the rim of the crown.

Sand filter. A bed of sand through which water is permitted to pass to reduce the amount of silt, plankton, colloidal material and related substances that were present in the water. It is in common use in water-treatment plants.

Saprophytic. The capability by some plants, including certain bacteria and molds, of utilizing dead organic matter as nutrients.

Schmutzdecke. A German term for "filter skin": the gelatinous layer over the top of a slow sand filter and containing various types of aquatic microorganisms.

Sedgewick-Rafter method. A procedure for the quantitative determination of plankton in water, involving the use of a special funnel and a special counting slide.

Sedimentation. A phenomenon used in water and sewage treatment in which the rate of flow of the water is reduced or stopped, permitting the settling out by gravitation of the suspended particles.

Semirigid. A structure capable of limited change in form.

Sewage. The spent water supply after it has received the various household, industrial and other wastes of a community.

Sewage treatment. Any artificial process to which sewage is subjected in order to remove or reduce its objectional constituents.

Slow sand filter. A bed of sand for water treatment constructed to permit water to flow through it at a relatively slow rate. The rate is commonly from 3 to 6 million gallons per day per acre of filter surface area.

Stabilization. Biological transformation of organic wastes into more durable metabolic end products.

Stabilization pond. An enclosure for sewage designed to promote the intensive growth of algae. These organisms provide oxygen that stimulates transformation of the wastes into inoffensive end products.

Strand. A cylindrical, stem-like plant body that is more than one cell thick.

Striae. Lines of pores (appearing as dots) arranged in a regular pattern in the walls of diatoms.

Subspherical. Almost spherical.

Surface water. Water that rests upon the surface of the earth in contrast to ground water.

Symmetrical diatom. Correspondence in shape, size and relative position of parts of the two longitudinal or transverse halves of a diatom.

Taste. A type of sensation (such as sweet or bitter) that the tongue recognizes in addition to texture and temperature of a substance.

Taxonomic. Emphasis on the classification and identification of organisms.

Thallus. The plant body of an alga or fungus, composed of one or more cells.

Threshold odor number. A unit designating the intensity of odor in water as determined by its perception in a series of dilutions with odor-free water.

Tongue sensation. The feel or texture that the tongue registers when in contact with water containing various solutes. This is in addition to the sensations of taste and temperature.

True branching. An elongated lateral growth initiated by the longitudinal division of a marginal cell or cells in a filament or strand.

True raphe. A slit (appearing as a line) extending almost the length of the valve face of a diatom and interrupted in the middle by a nodular area. The raphe is bounded by a clear area which, in turn, is bounded by striae.

Tube. A thread-like plant body, one cell wide, that is not divided into segments by cross walls.

Unbound carbonates. The soluble carbonic acid present in water where a balance is maintained between the amounts of bound, half bound and unbound carbonates.

Unialgal culture. A growth of only one kind of alga in an artificial nutrient medium, but not necessarily free of other types of microorganisms such as bacteria and protozoa.

Unicell. An organism composed of an isolated single cell.

Unicellular. One celled.

Unsymmetrical diatom. Lack of correspondence in shape, size and relative position of parts in the two longitudinal or transverse halves of a diatom.

Vacuole. An area within a protoplast which contains a liquid such as cell sap or oil.

Valve view. The top surface, rather than the side, of the epitheca or hypotheca of a diatom.

Water mites. Small, sometimes microscopic aquatic organisms with a more or less round unsegmented body and with four pairs of legs and one pair of palpi (processes attached to the mouth).

Water quality. Those characteristics of a supply of water which are important in determining its purity and usefulness to man.

Water table. The surface of a body of ground water when its level is not confined by any overlying impermeable layer of rock or soil.

Whipple micrometer. A subdivided square, marked off on a glass disc, that fits into the microscope ocular. At a magnification of 100X, in many microscopes, the square covers approximately 1 sq. mm. of the microscope field. It is designed for use in plankton counting.

Whorled branching. More than two branches per node or at any one height on a filament or strand.

Yeast. Unicellular fungi which in general commonly reproduce by budding, and ferment one or more carbohydrates with the production of gas.

Zooplankton. Protozoa and other animal microorganisms living unattached in water.

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